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American Heart Journal

VOL. 49 JANUARY, 1955 No. 1

Original Communications

THE VALUE OF BLOOD VOLUME DETERMINATIONS IN THE STUDY OF PATIENTS UNDERGOING SURGERY FOR RHEUMATIC HEART DISEASE

WILLIAM LIKOFF, M.D., DONALD BERKOWITZ, M.D.,
SAMUEL GEYER, M.D., HERBERT STRAUSS, A.B.,
AND ATTILIO REALE, M.D.

PHILADELPHIA, PA.

INTRODUCTION

THE recent availability of radioactive substances has led to new methods for the determination of circulating blood volume. A technique based on utilizing radioiodinated (I^{131}) human serum albumin (RISA)* is practical for clinical application. It affords a means of measuring plasma volume directly and is more valid for such study than the methods which rely upon calculations derived from the red cell volume and the venous hematocrit.[1] Current investigation strongly supports the contention that radioiodinated serum albumin (RISA) does not escape from the vascular system in sufficient quantity to mar the accuracy of the direct measurement.[2-4] Studies employing the RISA method have shown a consistent elevation of blood volume in patients with congestive heart failure.[1]

In surgery for acquired heart disease, the morbidity and mortality increase when decompensation is present.[5,6] The relation of functional integrity to patient recovery unquestionably varies with the severity of failure. However, it is likely that the lesser degrees of decompensation which may escape clinical detection significantly influence the risks of surgery.

Since total blood volume appears to reflect the functional state of the heart, this study was undertaken to establish the usefulness of such a determination in the selection of patients for cardiac surgery and in indicating the optimum time for operation.

From the Departments of Medicine, Radiology, and Thoracic Surgery of the Hahnemann Medical College and Hospital, and from the Bailey Thoracic Clinic, Philadelphia, Pa.

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*Obtained from the Abbott Laboratories, Oak Ridge, Tennessee.

METHOD

The blood volume was determined with the patient fasting and in a basal state. Radioactive-iodinated (I^{131}) human serum albumin (RISA) was used according to the technique of Storaasli and his associates,[7] with certain modifications.

A sample of blood was withdrawn from an arm vein by means of a special indwelling needle, and 30 to 40 μc of radioactive-iodinated albumin (RISA) contained in 10 c.c. of normal saline were injected. Two samples of blood were withdrawn, ten and twenty minutes later, respectively.

A standard of the isotope was prepared by diluting 1 c.c. of the diluted radioactive-iodinated albumin (RISA) solution with water to 100 c.c.

The venous hematocrit was determined from the preinjection blood sample and was corrected by the factor 0.915 to account for plasma trapped with red cells.[8]

With the use of standard planchets, 0.5 c.c. of the standard solution was mixed with 0.5 c.c. of the preinjection plasma, and its activity was compared with 0.5 c.c. of the postinjection plasma diluted with 0.5 c.c. of water. The planchets were dried in an oven to a thin film. Counting was accomplished under a mica end-window Geiger tube.

The plasma, red cell, and total blood volumes were calculated from the following formulas:

$$\text{Plasma volume} = \frac{\text{Activity of Std.} \times \text{Dilution of Std.} \times \text{Vol. injected}}{\text{Activity of sample}}$$

$$\text{Total blood volume} = \frac{\text{Plasma volume}}{1 - \text{Hematocrit} \times 0.915}$$

$$\text{Red Cell Volume} = \text{Total blood volume} - \text{Plasma volume}$$

For the purposes of this study the term morbidity refers to the development of congestive heart failure following surgery during the period of hospitalization which averaged eighteen days. The term mortality refers to death resulting only from a cardiac cause. Fatalities secondary to surgically induced hemorrhage, embolic issue, ventricular fibrillation, or unrelated complications are not considered in the statistical analysis in view of the purposes of this investigation. In all patients who came to surgery, a determination was made approximately twenty-four hours prior to operation.

MATERIAL

Forty-five normal subjects and one hundred patients with rheumatic heart disease were studied. The latter included patients with single and combined valve lesions. The one hundred patients with rheumatic heart disease were divided into the following groups:

Group 1 consisted of fifty-four patients who had no clinical evidence of congestive failure.

Group 2 included twenty patients studied while in obvious congestive failure.

Group 3 consisted of twenty-six patients in whom the classic manifestation of decompensation had disappeared while undergoing therapy in the hospital. Although studies may have been made in some of these subjects during failure, the final determinations from which the average values were obtained in this group were performed only when compensation had been established clinically.

Group 4 included eleven patients selected from Groups 2 and 3 in whom blood volumes were calculated serially during the treatment period for decompensation. A total of thirty-four determinations were obtained on the patients in this group.

RESULTS

1. *Normal Subjects.*—The average total blood, plasma, and red cell volumes are listed in Table I. These results are in accord with prior investigations.[7, 9]

TABLE I. PLASMA VOLUME, RED CELL VOLUME, AND TOTAL BLOOD VOLUME IN NORMAL AND RHEUMATIC HEART DISEASE PATIENTS

	NO.	PLASMA VOLUME (C.C./KG.)	RED CELL VOLUME (C.C./KG.)	TOTAL BLOOD VOLUME (C.C./KG.)
Normals	45	39.6 ± 5.8	35.6 ± 5.3	75.1 ± 9.9
Group 1	54	36.6	37.3	73.9
Group 2	20	51.0	49.3	100.3
Group 3	26	42.8	43.8	86.0

On the basis of this study the total blood volume in the other groups was considered normal if it fell below 90 c.c. per kilogram of body weight. This figure represents the average normal blood volume (75.1 c.c. per kilogram) plus one and one-half times the standard deviation (9.97). The upper normal limit for plasma volume was calculated to be 48.3 c.c. per kilogram, and for red cell volume, 44.3 c.c. per kilogram.

2. *Group 1.*—The average plasma, red cell, and total blood volumes in the fifty-four patients with rheumatic heart disease who had no clinical evidence of failure are listed in Table I. Included in these values are the results in three patients whose total blood volumes were abnormally high. In two subjects this abnormality was the result of elevations in both red cell and plasma values, and in one, the result of an increase in red cell volume.

3. *Group 2.*—The average plasma, red cell, and total blood volumes in the twenty patients studied in the presence of decompensation are indicated in Table I and exceed the normal by 25.2 c.c. per kilogram. This marked increase was observed even though four of the patients had normal values. Of the sixteen elevations, eight had abnormal plasma and red cell volumes, five had high red cell levels, and three had increases in the plasma volume alone.

4. *Group 3.*—The average total blood volume in this group fell within normal limits (Table I). This result was obtained in spite of the fact that fourteen of the twenty-six patients had abnormally high levels. Six of these patients had rises in both plasma and red cell volumes, five in red cell volume, and three in plasma volume.

5. *Group 4.*—Typical changes in total blood volume in two patients during therapy for decompensation are illustrated in Fig. 1. Initially, the values in each of the eleven patients studied serially were increased and ranged from 92.4 c.c. to 131 c.c. per kilogram.

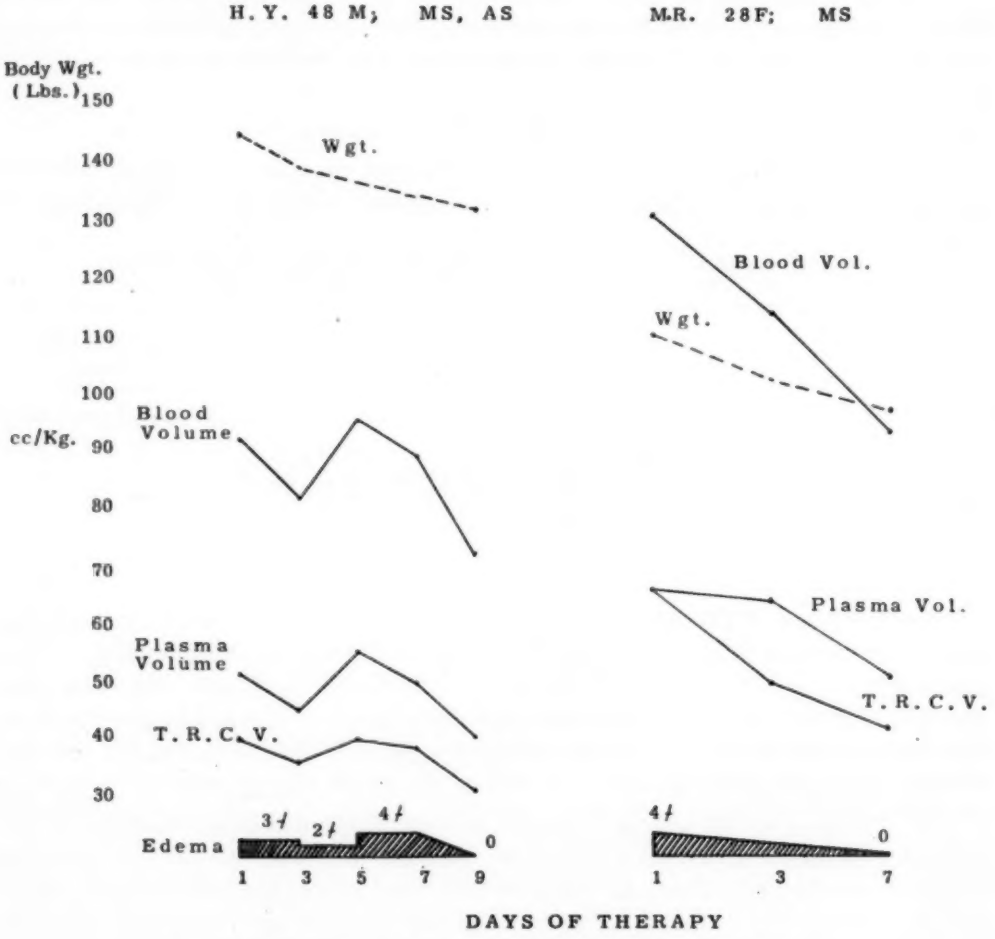

Fig. 1.—Blood volume changes during therapy for congestive failure.

Nine of the patients had a progressive fall in total blood volume. In three, the final determination exceeded normal figures, but two of these patients continued to have manifestations of failure.

A small but actual rise in total blood volume, the result of increases in red cell and plasma volumes, was noted in one patient. In another, the total blood volume remained unchanged because an increase in red cell volume compensated for a fall in the plasma volume.

Viewed differently, eight of the eleven patients were restored to compensation, and in five of these the total blood volume returned to normal limits. In two of the remaining cases, the total blood volume either remained the same, or increased. The third patient showed a progressive decline in total blood volume which did not reach normal limits.

Only a single patient of those followed serially was observed to have a normal total blood volume after therapy when signs of failure were still present. A progressive fall from 98 to 66.7 c.c. per kilogram occurred as the manifestations of advanced failure gradually disappeared. However, at the time of death, the result of acute pulmonary edema, peripheral edema persisted.

6. *Prognosis Related to Blood Volume.*—A total of eighty-five (Table II) patients were operated upon, twenty-six of whom had elevated blood volumes.

TABLE II. RELATION OF TOTAL BLOOD VOLUME (TBV) TO MORTALITY AND MORBIDITY

	NO. OPERATED	DEATHS	MORBIDITY	COMBINED MORTAL. + MORBID.	PER CENT
Group 1					
Normal TBV	45	1	—	1	2.2
Elevated TBV	3	1	1	2	66.7
Group 2					
Normal TBV	2	—	—	—	—
Elevated TBV	9	1	4	5	55.6
Group 3					
Normal TBV	12	1	1	2	16.6
Elevated TBV	14	2	6	8	57.1
Totals					
Normal TBV	59	2	1	3	5.6
Elevated TBV	26	4	11	15	57.7

Of the fifty-nine patients with a normal total blood volume, two died and one developed congestive heart failure for a combined morbidity-mortality of 5.6 per cent. Four of the twenty-six patients with an elevated total blood volume died following surgery, and eleven developed decompensation for a combined morbidity-mortality of 57.7 per cent. When the total number of patients operated upon was classified according to the groups already outlined, a significant increase in morbidity and mortality was observed in each group for those subjects with elevated total blood volumes.

Because of the possible influence of the valvular lesion and type of surgical procedure on the morbidity and mortality, the patients were classified accordingly (Table III).

Of the twenty-eight patients with mitral stenosis who had a normal blood volume, one developed congestive heart failure for a combined morbidity-mortality of 3.5 per cent. However, five of the eight patients with the same lesion

and an elevated blood volume developed heart failure for a combined morbidity-mortality of 62.5 per cent. None of the sixteen patients with aortic stenosis who were studied died or developed failure. There were two deaths in the thirteen patients with combined aortic and mitral disease who had normal blood volumes for a morbidity-mortality of 15.4 per cent. Three of the sixteen patients with identical valve lesions and elevated blood volumes died, and six developed congestive failure for a combined morbidity-mortality of 56.2 per cent. Of the four cases with mitral insufficiency, death occurred in the one patient who had an elevated blood volume.

TABLE III. RELATION OF TOTAL BLOOD VOLUME TO OPERATIVE MORTALITY AND MORBIDITY ACCORDING TO DIAGNOSIS

DIAGNOSIS	NORMAL BLOOD VOLUME					ELEVATED BLOOD VOLUME				
	NO.	DEATHS	MORBID.	COMBINED MORTAL. + MORBID.	PER CENT	NO.	DEATHS	MORBID.	COMBINED MORTAL. + MORBID.	PER CENT
MS	28	—	1	1	3.5	8	—	5	5	62.5
AS	15	—	—	—	—	1	—	—	—	—
Combined*	13	2	—	2	15.4	16	3	6	9	56.2
MI	3	—	—	—	—	1	1	—	1	100.0

*Refers to combined aortic and mitral valvular lesions.

DISCUSSION

Although the mechanism responsible for the expansion of total blood volume in congestive heart failure is obscure, the usefulness of the determination in surgery for acquired heart disease rests with its ability to indicate a breakdown in compensation which escapes clinical detection and yet significantly influences the morbidity or mortality following operation. This problem arises infrequently in patients who have never been decompensated, but it is common in those who have had marked manifestations of failure and appear to have responded to treatment, as adjudged by clinical evaluation, as well as in patients who are in the early phases of failure.

This study, based on the use of radioactive-iodinated albumin (RISA), corroborates previous investigations which have indicated an increase in total blood volume when decompensation is present. Only four false-negative results were obtained. In two of these patients the values were borderline. In the third, the measurement had fallen from a previously high value while the patient was under rigorous therapy for failure. Actually, therefore, the test was grossly misleading in only one of twenty patients who presented the characteristic clinical picture of congestive failure.

In the one unquestioned false-negative, the total blood volume was 79 c.c. and 70 c.c. per kilogram on two separate determinations in spite of the most advanced signs of congestive failure, including Grade 4 peripheral edema. Since death occurred within four days of hospitalization, it was impossible to record the alterations in total volume during diuretic therapy. It is conceivable that

a phase of congestive failure characterized by marked peripheral edema is not associated with an increase in blood volume, and that an elevation does not occur until therapy results in a transport of fluid from the cellular to the vascular space. Serial determinations in patients under treatment did not reveal further examples of this possibility. In no instance, however, was the peripheral edema as severe as in the case cited. One patient did reveal an actual increase, but in an initially elevated blood volume during the early phase of therapy when peripheral edema disappeared.

The present investigation demonstrated that the total blood volume was normal in 95 per cent of the patients with chronic rheumatic heart disease who had never been decompensated. In the remaining 5 per cent, the increase in total blood volume apparently was not a false-positive result, inasmuch as the morbidity-mortality following cardiac surgery was strikingly similar to that seen in patients with the usual manifestations of decompensation. The observation implies that an elevated total blood volume without clinical confirmation of heart failure may, nevertheless, reflect important changes in cardiac physiology capable of interfering with the desired benefits or survival following operation. It likewise suggests that blood volume changes may precede the gross clinical expressions of decompensation.

In over one-half of the patients in whom a single determination was made at the conclusion of treatment for congestive failure, the blood volume remained high at the time the clinical signs of decompensation disappeared. The same observation was made in three of eight patients who were studied serially during treatment. It is unlikely that these increased values represented false-positive results since the morbidity-mortality following surgery in these patients was similar to that noted in the presence of frank decompensation.

The explanation of the maintained elevation may rest with the continuing vascular transport of fluid formerly retained in the cells. In such cases, further therapy may have resulted in a satisfactory reversal of the abnormal levels. On the other hand, the inability to attain a normal blood volume after adequate therapy suggested that heart disease is advanced beyond the point of response to ordinary therapeutic measures. In either case, clinical considerations failed to uncover the physiologic issue. Furthermore, it was clear that such patients represented poor risks for surgical intervention.

Elevations in the total blood volume resulted from an increase in the red cell value, plasma level, or both. There was no indication in this study that the clinical pattern of decompensation varied in either case. In addition this fact did not influence the morbidity or mortality rates.

In view of the observations made in this study, it appears proper to suggest that cardiac surgery for acquired heart lesions be delayed in all patients until the total blood volume is within normal limits. This is particularly true in those patients who offer a significant history of congestive failure, or who present themselves with the manifestations of decompensation. The increase in the morbidity and mortality is identical for patients with an expanded blood volume independent of the clinical signs of failure. In patients with obvious decompensation, a normal blood volume cannot be accepted as an indication for surgery prior to the stabilization of the clinical picture.

CONCLUSIONS

1. Radioactive-iodinated (I^{131}) human serum albumin (RISA) provides an adequate and practical substance for determination of total blood volume.

2. The average total blood volume in forty-five normal individuals was 75.1 c.c. per kilogram.

3. The average total blood volume in fifty-four patients with compensated rheumatic heart disease was within normal limits.

4. The average total blood volume in twenty patients with congestive failure was elevated above that of the normals and fell progressively as compensation was restored in nine of eleven subjects studied serially.

5. Normal values were obtained in only four of the twenty patients with obvious decompensation. Possible explanations for these false-positive results are described.

6. Regardless of the clinical picture, the morbidity and mortality of patients with elevated total blood volumes who were operated upon for acquired heart disease were sharply increased beyond normal expectations.

REFERENCES

1. Schreiber, S. S., Bauman, A., Yalow, R. S., and Berson, S. A.: Blood Volume Alterations in Congestive Heart Failure, J. Clin. Invest. **33**:578, 1954.
2. Schultz, A. L., Hammarsten, J. F., Heller, B. I., and Ebert, R. V.: A Critical Comparison of the T-1824 Dye and Iodinated Albumin Methods for Plasma Volume Measurement, J. Clin. Invest. **32**:107, 1953.
3. Berson, S. A., and Yalow, R. S.: The Use of K^{42} or P^{32} Labeled Erythrocytes and I^{131} Tagged Human Serum Albumin in Simultaneous Blood Volume Determinations, J. Clin. Invest. **31**:572, 1952.
4. Moir, T. W., Ford, A. B., and Pritchard, W. H.: The Study of the Early Disappearance of Iodinated (I^{131}) Serum Albumin From the Circulation of Edematous Subjects by a Continuously Recording Method. Presented at the 26th Annual Meeting of the Central Society for Clinical Research, October 30 and 31, 1953, Chicago.
5. Blank, E. F.: Surgery for Mitral Stenosis. A Review of Progress, Circulation **5**:290, 1952.
6. Bailey, C. P., Bolton, H. E., and Redondo-Ramirez, H. P.: Surgery of the Mitral Valve, S. Clin. North America **32**:807, 1952.
7. Storaasli, J. P., Krieger, H., Friedell, H. L., and Holden, W. D.: The Use of Radioactive Iodinated Plasma Protein in the Study of Blood Volume, Surg., Gynec. & Obst., **91**:458, 1950.
8. Mayerson, H. S., Lysons, C., Parsons, W., Nieset, R. T., and Trautman, W. V., Jr.: Comparison of Results of Measurements of Red Blood Cell Volume by Direct and Indirect Techniques, Am. J. Physiol. **155**:232, 1948.
9. Brady, L. W., Cooper, D. Y., Colodzin, M., McClenathan, J. E., King, E. R., and Williams R.: Blood Volume Studies in Normal Humans, Surg., Gynec. & Obst. **97**:25, 1953.

THE RELATIONSHIP BETWEEN SUDDEN CHANGES IN WEATHER AND THE OCCURRENCE OF ACUTE MYOCARDIAL INFARCTION

H. C. Teng, M.D., and Howard E. Heyer, M.D.

Dallas, Texas

INTRODUCTION

MAN is not immune to his meteorologic environment. More than 2,400 years ago, Hippocrates[1] recognized the importance of the effect of weather and climate on the human being. Numerous authors in recent decades have called attention to the possible relationship of sudden changes in weather to the development of various disease states.[2-6] There has, however, been a paucity of data concerning the relationship between sudden changes in weather and the development of acute myocardial infarction. Peterson has called attention to the effect of sudden changes of temperature in this regard.[7,8] However, no large series of proved cases of acute myocardial infarction has been analyzed with a view to relating the time of onset to the weather conditions existent within that period. It is the purpose of the present paper to report certain general tendencies involving acute changes in weather which appear to bear a relationship to the onset of acute myocardial infarction.

METHOD OF STUDY

The present study of relationship between change in weather and onset of acute myocardial infarction was made in Dallas, which is located in north central Texas, approximately 250 miles inland from the Gulf of Mexico. Its climate is characterized by quite hot summers, rather mild winters, and the frequent occurrence of sudden changes in temperature and humidity. A survey of cases of acute myocardial infarction was made in three Dallas hospitals (Dallas City-County Hospital, Baylor University Hospital, and Methodist Hospital) from January, 1946, to December, 1951. The total number of admissions in that period was 283,931. Of this group, 1,666 cases were diagnosed as having acute myocardial infarction. In 1,386 of these cases, a critical review of the hospital records seemed to establish the diagnosis beyond any reasonable doubt. The criteria utilized in making the diagnosis consisted of (1) a clinical history of chest pain, (2) typical or highly suggestive electrocardiographic findings, (3) clinical

From the Department of Internal Medicine, Southwestern Medical School of the University of Texas, Dallas, and from the Dallas City-County, Baylor University, and Methodist Hospitals of Dallas.

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and laboratory signs of tissue death compatible with infarction, and (4) whenever obtainable autopsy confirmation of the diagnosis. Each case was carefully reviewed, and the time of onset of infarction was recorded. In 280 cases the clinical data were not adequate to substantiate the diagnosis, and these cases were excluded from the survey. The cases finally included in this series were those in which a clinical diagnosis of acute myocardial infarction was established. Numerous cases of so-called coronary insufficiency were recognized in the course of the survey but were excluded from this study.

Detailed meteorologic data[9-10] were obtained from the Dallas Weather Bureau. Daily variations in weather, including temperature, barometric pressure, and relative humidity, were plotted at six-hour intervals. Sunshine, sky cover, precipitation, wind direction, and velocity were plotted for twenty-four-hour periods. These data were recorded for the period from 1946 to 1951, inclusive. The occurrence of cases of acute myocardial infarction was charted, along with the variables showing the weather conditions existent at that time. Thus, it was possible to relate the time of onset of acute myocardial infarction to the weather conditions existent at any given period.

RESULTS

During the period from 1946 to 1951 (a period of 2,191 days) a total of 1,386 patients with acute myocardial infarction were admitted to the three Dallas hospitals included in this study. Of the patients 1,015 were male, and 371 were female. There was a total of 340 deaths, an over-all mortality rate of 24.5 per cent.

A survey of the meteorologic data revealed that, in general, five types of climatic conditions were found to prevail. These were as follows: (1) days of stable meteorologic conditions; (2) days characterized by a sudden onset of cold weather with a precipitous fall in temperature (polar inflow); (3) days characterized by a sudden onset of warm weather (tropical inflow); (4) long periods of continued and excessive hot weather; and (5) days characterized by rain, sleet, or snow (precipitation). The relationship between these various types of weather and the occurrence of cases of acute myocardial infarction formed the basis for the present study.

1. *Stable Meteorologic Conditions.*—These days were characterized by an absence of any sudden major change in atmospheric temperature, humidity, or barometric pressure. They also included cold, clear days which were free of precipitation and sudden changes in temperature. During the six-year period of study, a total of 782 days were characterized by such stable meteorologic conditions. A total of 375 cases of acute myocardial infarction were found to have their onset on these days of stable weather. The average daily admission rate for acute myocardial infarction was 0.48 patients during the days characterized by such stable weather (Fig. 1).

2. *Effect of Sudden Onset of Cold Weather (Sudden Inflow of Polar Air.)*—Since Dallas is located in the lower middle latitudes between the source regions of the cold dry Canadian and moist warm Gulf air, it is quite common to have sudden abrupt changes in weather. Sudden inflows of large bodies of cold air (polar inflows) are frequent between October and April. Such inflows of polar air are accompanied by north or northwest winds and give rise to a sudden drop in atmospheric temperature and a rapid elevation of barometric pressure. After several days of relatively cold weather the temperature then usually rises and the barometric pressure falls simultaneously.

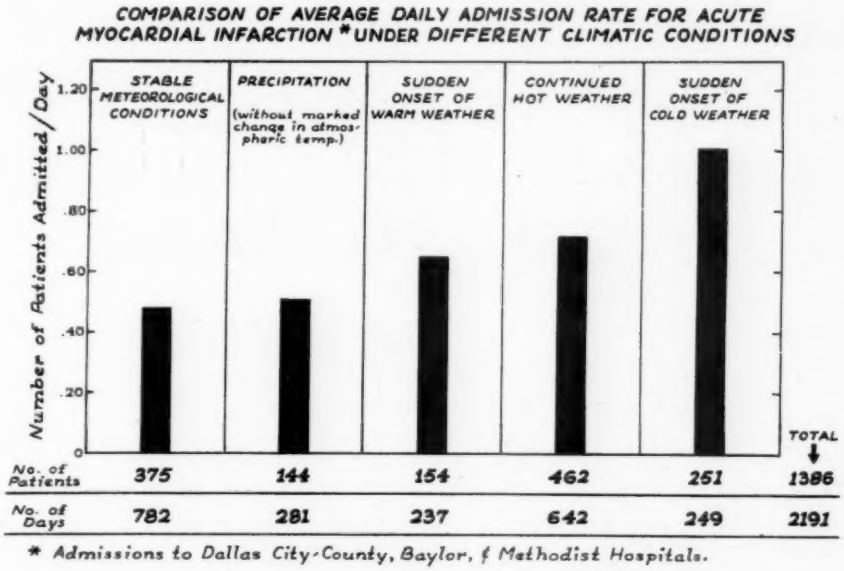

Fig. 1.

In this survey of the period from 1946 to 1951, one of the major trends noted was the tendency for acute myocardial infarction to occur during or shortly following the sudden inflow of polar air. The average daily fluctuation between the maximum and minimum temperature during this six-year period was found to be 22° F. The sudden inflow of cold air, however, would often cause much greater drops in temperature with a fall in temperature frequently exceeding 35° F. During a period of twelve to forty-eight hours from the onset of the polar inflow, it was noted that cases of acute myocardial infarction would frequently occur. Reference to Figs. 2, 3, 4, and 5 shows striking examples of the association of acute myocardial infarction with such polar inflows. It will be noted that in each case the inflow was accompanied by a simultaneous elevation of barometric pressure and that north or northwest winds almost always prevailed to bring in these polar air masses.

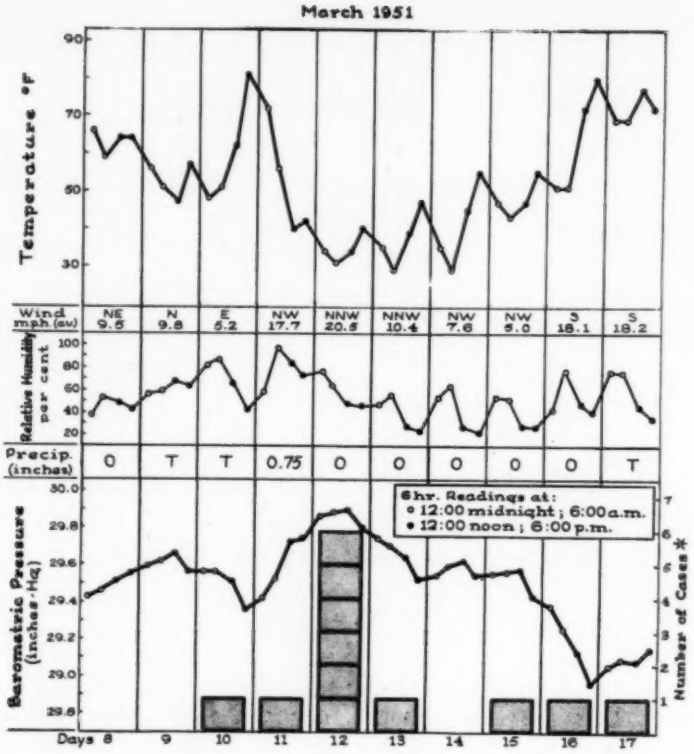
March 1951
Temperature °F
90
70
50
30
Wind mph (av)
NE 9.5
N 9.8
E 5.2
NW 17.7
NNW 20.5
NNW 10.4
NW 7.6
NW 9.0
S 18.1
S 18.2
Relative Humidity per cent
100
80
60
40
20
Precip. (inches)
0 T T 0.75 0 0 0 0 0 T
Barometric Pressure (inches-Hg)
30.0
29.8
29.6
29.4
29.2
29.0
28.8
6 hr. Readings at:
• 12:00 midnight ; 6:00 a.m.
• 12:00 noon ; 6:00 p.m.
Number of Cases *
7
6
5
4
3
2
1
Days 8 9 10 11 12 13 14 15 16 17

Fig. 2.

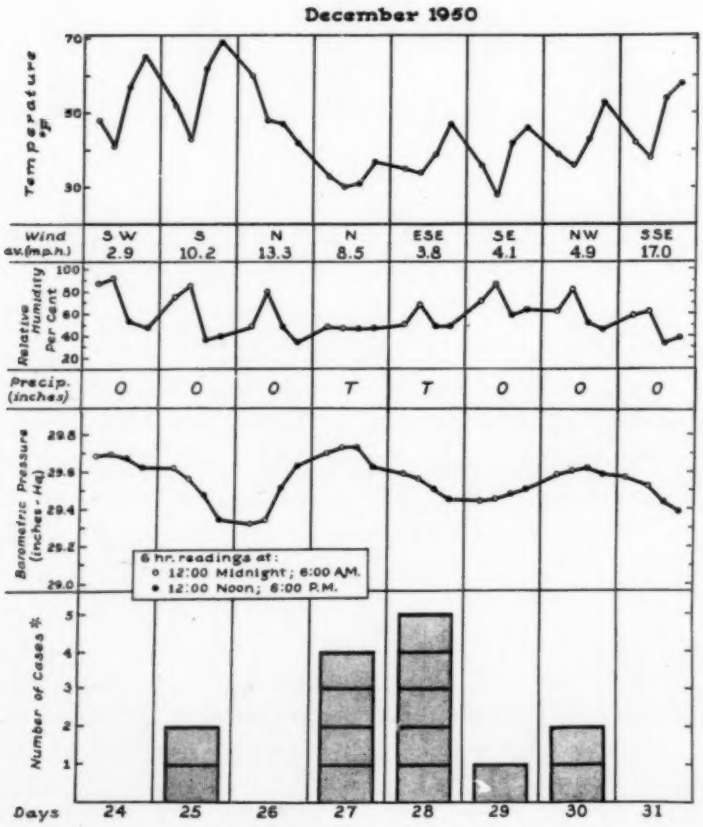
December 1950
Temperature °F
70
50
30
Wind av.(m.p.h.)
S W 2.9
S 10.2
N 13.3
N 8.5
ESE 3.8
SE 4.1
NW 4.9
SSE 17.0
Relative Humidity Per Cent
100
80
60
40
20
Precip. (inches)
0 0 0 T T 0 0 0
Barometric Pressure (inches - Hg)
29.8
29.6
29.4
29.2
29.0
6 hr. readings at:
• 12:00 Midnight ; 6:00 A.M.
• 12:00 Noon; 6:00 P.M.
Number of Cases *
5
4
3
2
1
Days 24 25 26 27 28 29 30 31

Fig. 3.

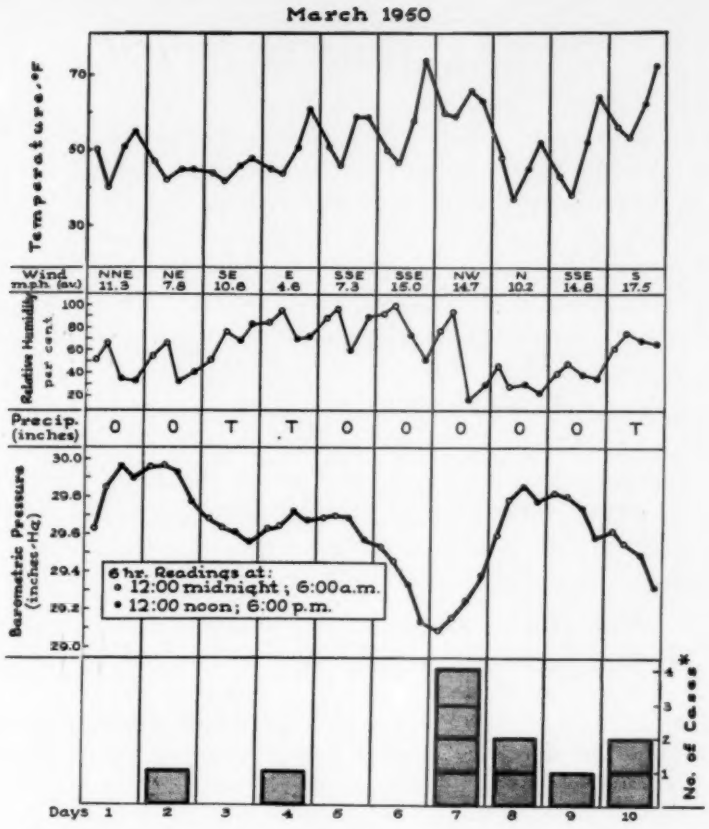

Fig. 4.

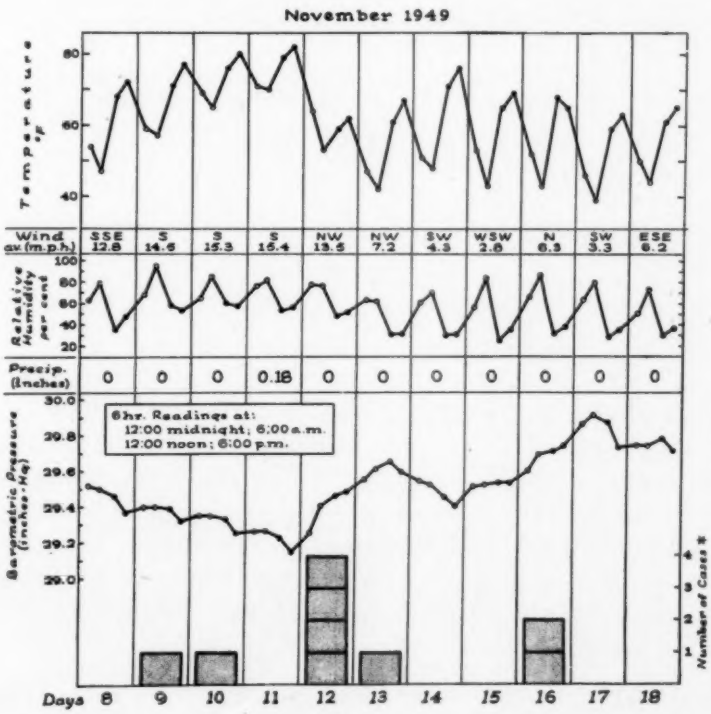

Fig. 5.

Figs. 2, 3, 4, and 5.—Illustrate the relationship between sudden inflow of polar air and onset of cases of acute myocardial infarction.

*Admissions to Dallas City-County, Baylor University, and Methodist Hospitals of Dallas.

During the period from 1946 to 1951, there were 114 episodes of major polar air inflow with sudden drops in temperature ranging from 36° to 62° F. within a period of fifteen to forty-eight hours. The average fall in temperature during these polar inflows averaged 43.2° F. (from maximum to minimum). The average increase of barometric pressure during these inflows of cold air was 0.55 inch of mercury. The majority of these episodes occurred during the winter (fifty-one episodes), with small numbers occurring during the autumn (thirty-four episodes) and spring (twenty-seven episodes), and very few in summer (two episodes).

During these periods of polar inflow, 251 patients developed acute myocardial infarction. About one-half of these attacks occurred during the early period of polar inflow, when the weather was still in the process of changing, with the atmospheric temperature decreasing and the barometric pressure rising. Other cases occurred during the hours immediately following the period of maximum fall in temperature.

In 122 instances, data were available concerning the activities of the patients at the time of onset of acute myocardial infarction. The mode of onset of the attacks during these periods of polar inflow is shown in Table I. It will be seen that the greatest number of patients suffered the onset of their illness while asleep or at rest. Physical activity in this group thus did not seem to be an important factor. Fifty-seven patients of the group that suffered the onset of acute myocardial infarction during cold weather died, a mortality rate of 22.7 per cent. This was not significantly different from the over-all mortality rate for the entire series, which was found to be 24.5 per cent.

TABLE I. RELATIONSHIP OF SUDDEN INFLOW OF POLAR AIR WITH THE MODE OF ONSET OF 122 CASES OF ACUTE MYOCARDIAL INFARCTION

MODE OF ONSET	NO. OF CASES (TOTAL)	NO. OF CASES (%)
Awakened from sleep and at rest	66	54.1
During and after minimal and moderate activity	33	27.0
After meals	23	18.9

As a measurement of the frequency of occurrence, the daily admission rate of patients proved to be suffering from acute myocardial infarction was computed. Reference to Fig. 1 and Table II will show that the daily admission rate (1.01) was greater during periods of polar inflow than during periods of stable meteorologic conditions. As a result of these studies, therefore, it appeared that acute myocardial infarction occurred more frequently during the rapid onset of cold weather. Statistical analysis indicated that this difference in frequency of occurrence was highly significant.

3. *The Effect of Sudden Onset of Warm Weather (Tropical Inflows).*—The weather of the Dallas area is also characterized by the occurrence of episodes of relatively sudden onset of warm weather. These are caused by a rapid inflow

of tropical air, carried by south or southeast winds, causing a rise in atmospheric temperature, and a simultaneous lowering of barometric pressure. These tropical inflows occur most frequently during the fall, winter, and spring of the year. In the present study, an inflow of south or southeast wind, associated with a sudden onset of warm weather, and giving rise to an elevation of atmospheric temperature of 36° F. or greater, was classified as a tropical inflow. These episodes usually occurred within a period of thirty-six to sixty hours.

TABLE II. STATISTICAL COMPARISON OF FREQUENCY OCCURRENCE OF CASES OF ACUTE MYOCARDIAL INFARCTIONS UNDER DIFFERENT CLIMATIC CONDITIONS IN DALLAS AREA—1946 TO 1951 INCLUSIVE

	NO. PATIENTS (TOTAL)	NO. DAYS (TOTAL)	PATIENTS PER DAY	STD. DEV. PATIENTS/ DAY	PROBABILITY AGAINST CHANCE OCCURRENCE OF DIFFERENCE IN INCIDENCE
Stable meteorologic conditions*	519	1063	0.49	±0.02	—
Sudden onset of warm weather	154	237	0.65	±0.05	>300 to 1†
Continued hot weather	462	642	0.72	±0.04	$>10^6$ to 1†
Sudden onset of cold weather	251	249	1.01	±0.06	$>10^{15}$ to 1†

*In present statistical analysis, this includes both stable meteorologic condition and days of precipitation without marked change in atmospheric temperature.

†Figures statistically significant.

From 1946 to 1951 inclusive, ninety such episodes of inflow of tropical air occurred. The average elevation in temperature during such an inflow was found to be 41° F. During these periods of relatively rapid inflow of tropical air, 154 cases of proved acute myocardial infarction occurred. The average daily admission rate was found to be 0.65 patients admitted per day (Fig. 1). When the admission rate was compared to that which prevailed during stable meteorologic conditions, there was a definite difference which appeared to be statistically significant (Table II). It thus appeared that sudden inflows of tropical air were also followed by a somewhat increased frequency of occurrence of acute myocardial infarction.

4. *The Effect of Progressive and Continued High Daily Temperature.*—The relationship between continued high daily temperatures and the occurrences of acute myocardial infarction has been reported elsewhere.[11] Reference to Fig. 6 reveals that when the seasonal occurrence is tabulated, the greatest number of attacks occurred during the summer months, and the lowest number of attacks occurred during the winter months. The increased frequency of this illness during the summer is different from previous reports from northern areas of the United States where the greatest number of attacks have frequently been found to occur during the winter months.[12,13] It should be recognized that the summer weather in the Dallas area is much warmer than that which generally prevails during the summer months in the northern United States.

From June until the middle of September, during this six-year period of observation, the average daily maximum temperature was 93.2° and the average daily minimum was 73° F. During these years, 462 cases of acute myocardial infarction occurred during the summer months. Reference to Table II and Fig. 1 reveals that the daily patient admission rate for acute myocardial infarction was significantly higher during these periods of continued hot weather than the admission rate prevailing during mild or stable meteorologic conditions.

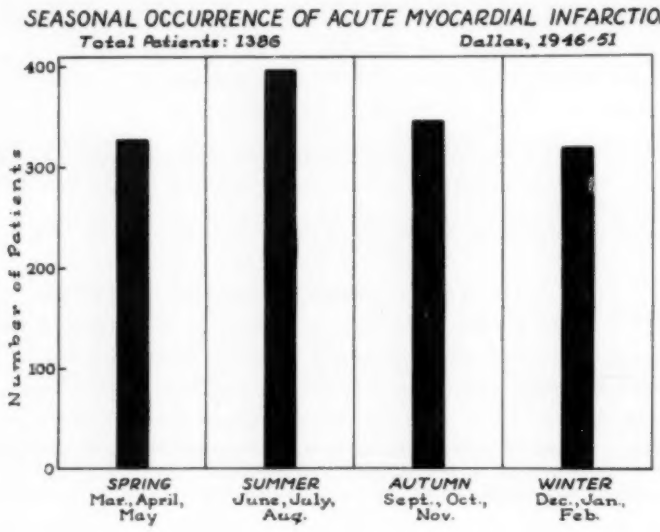

Fig. 6.

5. *Effect of Precipitation.*—The term precipitation includes weather featured by rainfall, sleet, hail, and snow. The Dallas patient admission rate for acute myocardial infarction was plotted during periods of precipitation and did not differ significantly from the admission rate prevailing under stable meteorologic conditions (Fig. 1). From this study, no marked change in the frequency of occurrence of acute myocardial infarction could be found during the periods of precipitation, provided that there were no associated marked changes in temperature or barometric pressure during the same period of time.

EFFECT OF SUDDEN CHANGES OF BAROMETRIC PRESSURE

Sudden changes of atmospheric temperature are always associated with sudden changes in barometric pressure. With any sudden inflow of polar air, barometric pressure rises and remains high during the period of polar inflow; conversely with the inflow of tropical air, a fall in barometric pressure occurs which will persist during the period of warm weather. With temperatures ranging around 30° F. the barometric pressure in the Dallas region is usually found to be in the neighborhood of 29.8 to 30.0 inches of mercury. When the atmospheric temperature ranges from 90° to 100° F. barometric pressures will usually be found to be in the neighborhood of 29.40 to 29.50 inches of mercury.

Since the inflow of polar air is characterized by the dual condition of low temperature and high barometric pressure, and since the opposite is true during periods of tropical air inflow, it is impossible to state with finality whether any observed changes are due to changes in barometric pressure per se. However, although possibly of great importance, it appears doubtful that the changes in barometric pressure, alone, are the only meteorologic factor responsible for the precipitation of acute myocardial infarction.

RELATIVE HUMIDITY

Relative humidity in the Dallas area, in general, is rather moderate. The monthly mean of average six-hour readings is around 60 to 70 per cent. However, there is a considerable daily fluctuation in the relative humidity which usually ranges from 60 to 80 per cent in the early morning, and 40 to 60 per cent in the afternoon. This variation in humidity is closely related to the fairly wide fluctuations in temperature which occur during any given period of twenty-four hours.

Changes in relative humidity did not seem to play an important role in the precipitation of acute myocardial infarction in this locality. Although this area is characterized by quite hot weather in the summer months, the relative humidity in the afternoon during hot days is moderate, averaging 48 per cent. The increased frequency of acute myocardial infarction in continued hot weather is, therefore, more probably due to elevated atmospheric temperature, rather than to alterations in humidity. The relative humidity is high on days with precipitation, but the patient admission rate for acute myocardial infarction during periods of precipitation, without marked changes of temperature, was not found to differ significantly from the admission rate prevailing under stable meteorologic conditions (Fig. 1). Thus, a majority of the polar inflows in the Dallas area, although associated with an increased occurrence of acute myocardial infarction, were generally not accompanied by high humidity or precipitation.

DISCUSSION

The results of the present study indicate a definite relationship between sudden changes in weather and the onset of acute myocardial infarction. An increased frequency of occurrence of acute myocardial infarction was observed during periods of sudden inflow of both polar air and tropical air masses (Fig. 1, Table II). This study confirms the observations of Peterson[7] who reported that the inflow of polar air often was accompanied by the development of acute myocardial infarction. Recently, Stroder and his associates[14] also found that in their sixty-three cases of acute myocardial infarction, fifty-five cases (87.3 per cent) appeared to develop coincidently with acute meteorologic disturbances.

Sudden changes in weather have also been observed to accompany the development of other types of acute thromboembolic phenomena and cardiovascular dysfunction. That patients with coronary sclerosis will develop angina in winter has been recognized for over 150 years, since the original communication of Heberden.[15] Newton[16] has reported the occurrence of phlebothrombosis

with the passage of meteorologic fronts. DeTakats and associates[17] noted that pulmonary embolism occurred more frequently during periods in the spring and fall, when marked barometric and thermal fluctuations occurred. Halse and Quennet[18] found that hyperprothrombinemia and thrombo-embolism occurred with a drop in barometric pressure. Stocks and others[19,20] have called attention to the association of sudden death from heart disease with high barometric pressure. Bundesen and Falk[21] reported, from a study of vital statistics and weather records in Chicago, that the combined mortality from organic diseases of heart, cerebral hemorrhage, and chronic nephritis was unusually high when the temperature was low. Berenson and Burch[22] observed an aggravation of the symptoms of congestive heart failure with an elevation in atmospheric temperature and humidity.

The exact mechanism by which sudden changes of weather may be related to the occurrence of acute myocardial infarction is unknown. Rapid onset of either cold or hot weather is always accompanied by simultaneous changes in wind velocity and direction as well as barometric pressure changes. In the present study, the increased tendency for acute myocardial infarction to occur apparently developed when the polar inflow brought a sudden drop of temperature of the magnitude of 36° F. or greater, within a period of approximately thirty-six hours or less. It is therefore possible that sudden change in environmental temperature per se was one of the main precipitating factors. In this connection it has been reported that exposure to cold produces many circulatory changes, including peripheral vasospasm, shivering, increased oxygen consumption, increased arteriovenous oxygen difference, and increased basal metabolism, as well as decreased plasma volume and decreased blood volume.[23-27]

When the mode of onset of cases of acute myocardial infarction is studied, however, it appears that cold is not the only meteorologic factor which may be important. Many of the patients had the onset of their symptoms of acute myocardial infarction either indoors, in a warm environment, during sleep, or at rest (Table I). About one-half of the cases occurred during the early period of polar inflow, when the temperature was still falling and the barometric pressure was continuing to rise. These facts suggest that other meteorologic factors, possibly including changes in barometric pressure, are operative, in addition to decreased temperature alone. The increase in barometric pressure during polar inflows averaged 0.55 inch or 13.97 mm. of mercury. It is possible that abrupt changes in barometric pressure of this magnitude exert an important influence in the precipitation of acute myocardial infarction.

Although the increase in occurrence of acute myocardial infarction following the inflow of large warm air masses (tropical inflows) was somewhat less striking than in the case of cold weather, nevertheless there appeared to be an increased frequency of occurrence of the disease with the sudden onset of warm weather. As in the case of the inflow of polar air masses, simultaneous changes in barometric pressure occur with the sudden advent of warm weather, the barometric pressure usually falling while the elevation in temperature takes place. Humidity also tends to change during a period of inflow of warm air. It is therefore difficult to ascribe a causative role specifically to temperature, barometric pressure, or humidity under these conditions.

The present study indicates that sudden meteorologic changes appear to exert an adverse effect on patients with coronary artery disease. It appears probable that the rapid onset of either cold or hot weather acts as a stress factor upon those patients with pre-existing coronary arteriosclerosis. The resultant physiologic adjustments that they must make to such changes evidently exert a considerable strain on the organism, and may produce alterations predisposing to an episode of acute myocardial infarction. The extent to which the various meteorologic factors act alone, or in combination, to produce these effects remains to be determined.

SUMMARY

An analysis of the relationship between the sudden changes in weather and the onset of cases of acute myocardial infarction was made in three Dallas hospitals, comprising a series of 1,386 patients admitted during a five-year period from 1946 to 1951. An increased frequency of occurrence of acute myocardial infarction was noted during periods of sudden inflows of polar and of tropical air masses. It appears from the present study that sudden meteorologic changes exert an adverse effect on patients with coronary artery disease.

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REFERENCES

1. Mark, E.: The Aphorisms of Hippocrates, New York, 1817, Collins & Co.
2. Fabricant, N. D.: Weather and the Climate, Am. J. M. Sc. **200**:835, 1940.
3. Fabricant, N. D.: The Climatic Factor in Precipitating Acute Tonsillitis in Children, J. Pediat. **15**:697, 1937.
4. Rentschler, E. B., Van Zant, F. R., and Rowntree, L. G.: Arthritic Pain in Relation to Weather Change, J.A.M.A. **92**:1995, 1929.
5. Brown, W. B., Mahoney, F., Niedringhaus, A., and Locke, A.: Weather and Susceptibility in Relation to the Spread of Common Cold: Effect of Ascorbic Acid, in Massive Dosage, on Duration, J. Immunol. **50**:161, 1945.
6. Mitchell, S. W.: The Relation of Pain to Weather, Am. J. M. Sc. **73**:305, 1877.
7. Peterson, W. F.: The Patient and the Weather, Vol. IV, Part 1, Ann Arbor, Michigan, 1937, Edwards Bros., Inc.
8. Peterson, W. F.: Organic Variability in Heart Disease, Postgrad. Med. **1**:36, 1947.
9. Station Meteorological Summary, Dallas,Texas, Weather Bureau, U. S. Dept. of Commerce 1946-1951.
10. Local Climatological Summary With Comparative Data, Dallas, Texas, Weather Bureau, U. S. Dept. of Commerce, 1951.
11. Heyer, H. E., Teng, H. C., and Barris, W.: The Increased Frequency of Acute Myocardial Infarction During Summer Months in a Warm Climate. A. Study of 1,386 Cases From Dallas, Texas, Am. Heart J. **45**:741, 1953.
12. Bean, W. B., and Mills, C. A.: Coronary Occlusion, Heart Failure, and Environmental Temperatures, Am. Heart J. **16**:701, 1938.
13. Brown, H. R., Jr., and Pearson, R.: Seasonal Variations in Heart and Coronary Disease as Related to Various Environmental Factors, Am. Heart J. **35**:763, 1948.
14. Ströder, U., Becker, F., and Haas, G.: Ueber die abhängigkeit des Herzinfarkteintrittes vom Wettergeschehen, Tagesrhythmus und von soloren Vorgängen, Klin. Wchnschr. **29**:312, 1951.
15. Heberden, W.: Some Account of a Disorder of the Breast, Med. Trans. Royal College of Physicians **2**:59, 1772.
16. Newton, M.: The Relationship of Weather to Post-operative Phlebothrombosis, Am. J. Surg. **81**:607, 1951.
17. DeTakats, G., Mayne, A., and Petersen, W. F.: Meteorologic Factor in Pulmonary Embolism, Surgery **7**:819, 1940.

18. Halse, T., Jr., and Quennet, G.: Klimatische Einflüsse in der Thrombogenese, Deutsche Med. Wchnschr. **73**:125, 1948.
19. Stocks, Percy: Brit. M. J. **2**:1188, 1925.
20. A. O. W., Brit. M. J. **2**:1098, 1925.
21. Bundesen, H. N., and Falk, I. S.: Low Temperature, High Barometer, and Sudden Death, J.A.M.A. **87**:1987, 1926.
22. Berenson, G. S., and Burch, G. E.: The Response of Patients With Congestive Heart Failure to a Rapid Elevation in Atmospheric Temperature and Humidity, Am. J. M. Sc. **223**:45, 1952.
23. Horvath, S. M., Golden, H., and Wager, J.: Some Observations on Men Sitting Quietly in Extreme Cold, J. Clin. Invest. **25**:709, 1949.
24. Adolph, E. F., and Molnar, G. W.: Exchanges of Heat and Tolerances to Cold in Men Exposed to Outdoor Weather, Am. J. Physiol. **146**:507, 1946.
25. Bazett, H. C., Sunderman, F. W., Doupe, J., and Scott, J. C.: Climatic Effects on the Volume and Composition of Blood in Man, Am. J. Physiol. **129**:69, 1940.
26. Conley, C. L., and Nickerson, J. L.: The Effects of Temperature Change on the Water Balance in Man, Am. J. Physiol. **143**:373, 1945.
27. Grollman, A.: The Cardiac Output of Man in Health and Disease, Springfield, Illinois, 1932, Charles C Thomas, Publisher.

THE EFFECTS OF PROGRESSIVE DAMPING AND OTHER TECHNICAL PROCEDURES ON THE DIRECT DISPLACEMENT BALLISTOCARDIOGRAM

WILLIAM T. TUCKER, M.D.,* AND ERIC J. OSTROM, M.D.

BIRMINGHAM, ALA.

THE present communication deals primarily with the effects of progressive damping on the direct ballistocardiogram. In addition, changes due to variation in body functions, recording surfaces, and pickup areas were studied.

METHODS

All tracings were made in a room with a concrete floor. The surfaces used were: (a) putty; (b) sand; and (c) a heavy wooden table. The sand was placed in a wooden box 2½ feet by 7 feet, to a depth of 5 inches, and covered with an ordinary bed sheet. The putty was a nonhardening caulking material sold under the trade name of "Flexiseal." Small amounts of sand and linseed oil were initially mixed with the putty to induce a convenient viscosity. The putty was placed in a box similar to that used with the sand. Occasional mixing of the putty was necessary, as it tended to maintain the impressions produced by the weight of the subjects. A thin plastic sheet was used to cover the putty. All records were obtained at the end of a normal expiration, with the breath held.

Recording Instruments.—A four-channel Sanborn Poly-Viso recorder and a four-channel Cambridge Simpli-scribe were used to record the tracings. All records of progressive damping were made on the former instrument.

The ballistocardiogram pickup was a bellows displacement apparatus, recording from the subject's head. This consisted of a small cylindrical metal bellows connected to a piezoelectric transducer by way of an air-conduction system, as described by Walker and associates.[1]

Simultaneous electrocardiograms, carotid and jugular pulse waves were recorded for timing purposes.

Progressive Damping.—Eight healthy young adults were allowed to settle in putty until there were no further changes in the ballistocardiogram. At this point sandbags were placed against the feet and shoulders, and on the thighs and abdomen. Records were obtained with each addition until no further changes

From the Department of Medicine, Medical College of Alabama, Birmingham, Ala.

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*National Heart Trainee of the National Heart Institute, National Institutes of Health, U. S. Public Health Service.

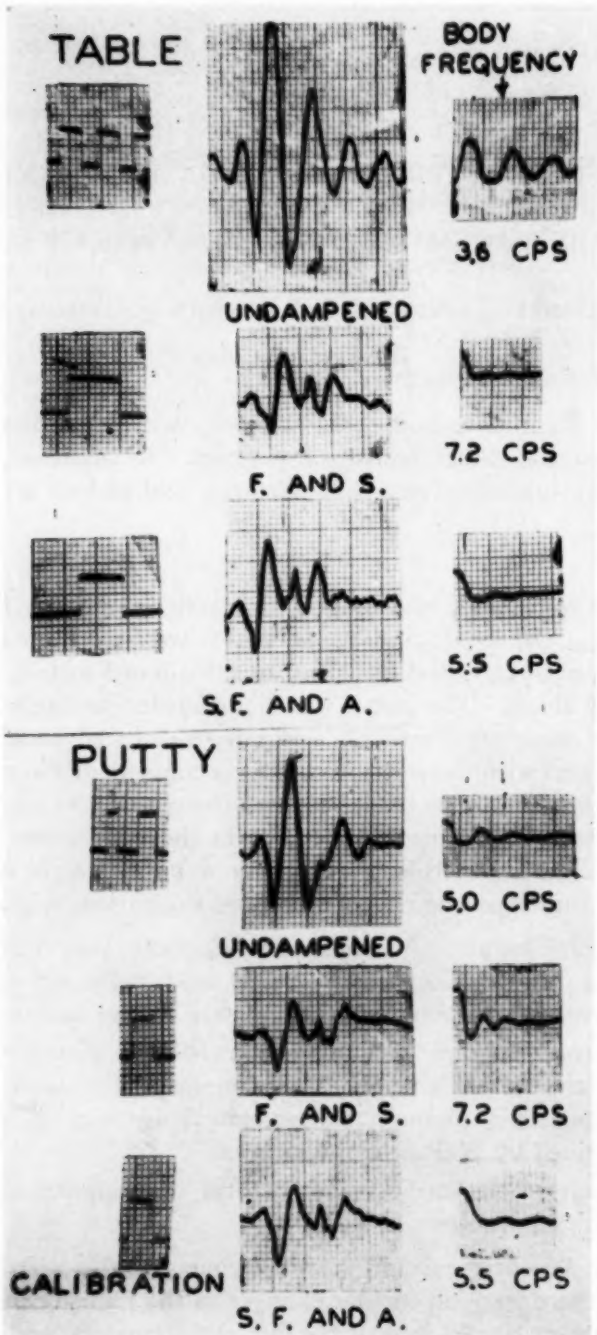

Fig. 1.—Records of normal subject lying on putty and table surfaces. Note decrease in amplitude when feet and shoulders are packed with sandbags. The K point is elevated and the J-K downstroke is slurred. A previously obscured K-L-M-N sequence becomes apparent when the feet and shoulders are packed. Body frequency is increased when sandbags are placed against the feet and shoulders and is decreased when additional bags are placed upon the body.

in configuration could be produced in the ballistocardiogram. Six canvas bags containing sand weighing 12½ pounds each, and four canvas sandbags weighing 25 pounds each, were used in this study.

Body frequencies were determined in ten normal young adult subjects on sand, putty, and table surfaces, with the varying degrees of damping mentioned here. The sensitivity of the recording apparatus was reduced until deflections produced by cardiovascular forces were not inscribed. The subject was then displaced cephalad by a force exerted with one finger on the heel of the subject. This force was then released and the resulting body vibrations recorded.

Nine subjects were studied, using only the putty surface, to determine the degree of damping achieved by packing the feet and shoulders with sandbags. In addition, body frequencies were measured. The degree of damping was obtained by measuring the amplitudes of deflections, X° and X^1 resulting from a force exerted by one finger on the heel. X° represents the initial headward force and X^1 the following footward force or after vibration. The degree of overshoot occurring in the footward wave is mathematically expressed as the coefficient being expressed as one.[3]

Head-Shin Recording Comparisons.—In an effort to obtain pure displacement tracings from the shins and to compare this method of pickup with the head-bellows pickup, an integrating and differentiating bar-magnet velocity meter* similar to that described by Smith[2] was used. Head-bellows displacement and shin bar-magnet transducer displacement were recorded simultaneously with and without elastic stockings on the shins in ten subjects.

Calibration and Standardization.—A mechanical sine wave generator with a known range of motion from 0.003 to 0.024 inch and a range of frequencies from 0.8 cycle per second to 5 cycles per second was used to test the lag of the ballisto-cardiographic pickups and to determine whether pure displacement was being recorded.

RESULTS AND CONCLUSIONS

A. *Surfaces.*—In studying several recording surfaces our results parallel closely those of Walker and associates.[1] The putty was noted to give diastolic waves that did not display progressive decrement but often had an increased amplitude in M-N (Fig. 1). The diastolic waves recorded on the table surface were changed as regards configuration and timing, while the early systolic waves were not significantly altered. The K nadir was usually noted to be high in the putty, thus decreasing the amplitude of the J-K downstroke. We attribute this to an increased damping effect of putty as compared to sand and the table, with the resultant increase in body frequency and diminution of aftervibrations. Consequently, putty was selected as the recording surface of choice. However, as suggested to us by Dr. William Dock, placing sandbags against the feet and shoulders of subjects on the table reduced the oscillatory patterns and transcribed

*Appreciation is expressed to the Sanborn Company for the loan of the integrating and differentiating bar-magnet velocity meter used in this study. This instrument is an early model and is not to be confused with a more recent model now being described by Smith, which eliminates the inherent lag and is of much lighter weight.

records quite similar in configuration to those recorded on the sand and putty surfaces (Fig. 2). However, because some subjects, even though packed with sandbags on the table, continued to produce an oscillatory type of ballistocardiogram, the remainder of our study was done using only the putty surface.

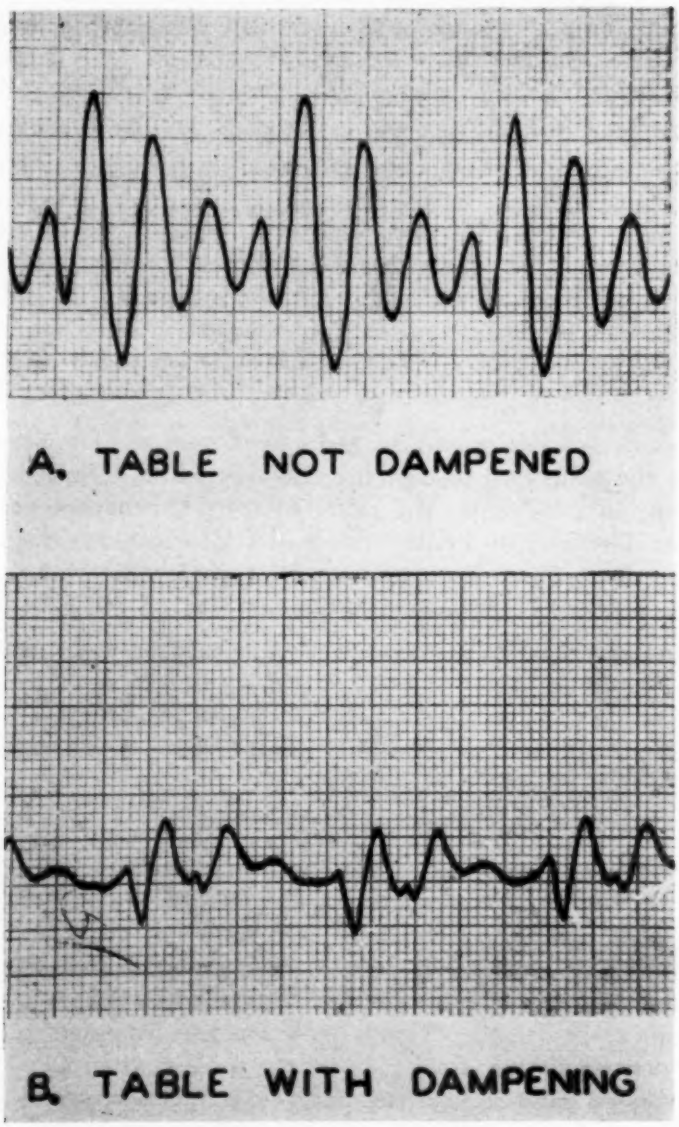

Fig. 2.—Comparison of direct ballistocardiogram on (*A*) table, subject not dampened, and (*B*) on table, subject dampened with bags against feet and shoulders. Note oscillatory pattern as manifested by progressive decrement in the size of the waves. Contrast this with (*B*) and note the shortened, slurred J-K downstroke with a high K nadir and the relative increase in height of the M-N upstroke and the H-I downstroke when compared to the I-J upstroke. During the 0.40 second following the I point in (*A*), two upward deflections are noted; in the same time interval in (*B*) three upward deflections are seen.

B. *Time Relationships.*—With the exception of the K point, progressive damping did not alter time relationships of any ballistocardiographic points to

known events of the cardiac cycle (Table I). The apparent time relationship of K did vary in a haphazard manner. This was directly related to the difficulty in establishing the K point. Such difficulty was occasioned by the slurring of the J-K downstroke when damping was increased (Fig. 1).

TABLE I

	Q-H	Q-I	H-Ce*	Ce*-I	H-I	L-CIN†	CIN-N
No sandbags	.10	.15	.03	.04	.07	.01	.13
Sandbags against feet and shoulders	.09	.16	.03	.04	.07	.01	.13
Additional sandbags placed on subject	.09	.16	.03	.03	.06	.01	.13

*Ce = Carotid ejection
†Cin = Carotid incisural notch
No significant changes in timing of ballistocardiogram waves, as related to the electrocardiogram and carotid pulse tracings, were noted with progressive damping. This table compares the average time intervals of several waves with varying degrees of progressive damping in ten normal subjects.

C. *Amplitude Changes.*—At the time when no additional changes in configuration could be produced by further damping, significant changes in certain wave amplitudes became apparent. H-I and M-N, although actually slightly decreased in amplitude, became relatively increased after damping in comparison to I-J, and especially to J-K. Since the exact position of K could not be established with certainty in some of the damped records, the J-K and K-L waves are not tabulated. The H-I/I-J ratio increased in all eight subjects (Table II).

TABLE II

SUBJECTS	NO SANDBAGS	BAGS AGAINST FEET AND SHOULDERS	BAGS AGAINST FEET AND SHOULDERS AND ON THE THIGHS AND ABDOMEN
	H-I/I-J	H-I/I-J	H-I/I-J
BH	.39	.70	.80
EO	.35	.51	.58
BF	.32	.44	.43
PN	.22	.34	.46
BT	.38	.56	.44
IR	.11		.25
WD	.35	.38	.44
DB	.41	.41	.45

Comparison of the H-I/I-J amplitude ratios as the subject is progressively damped with sandbags. Note now the ratio becomes larger, indicating the greater stability of H-I.

Similarly, M-N also increased when compared to I-J in six of eight subjects, with no significant changes being produced in two (Table III). Fig. 1 revealed relatively slight reduction of the H-I amplitude after progressive damping, while the I-J amplitude decreased significantly the J-K amplitude even more so. The K-L upstroke became extremely small and often was notched. In most subjects K-L displayed the maximal decrease in amplitude as compared to records obtained without damping.

TABLE III

SUBJECTS	NO SANDBAGS	BAGS PLACED AGAINST FEET AND SHOULDERS	BAGS AGAINST FEET AND SHOULDERS AND ON THIGHS AND ABDOMEN
	I-J/M-N	I-J/M-N	I-J/M-N
BH	2.8	2.5	1.9
EO	4.1	2.4	2.1
BF	3.1	3.1	2.7
PN	1.9	1.9	1.6
BT		3.0	2.3
IR	3.0		1.7
WD	1.8	2.2	1.8
DB	2.2	2.4	2.2

This table is a comparison of the I-J/M-N amplitude ratios with various degrees of damping. Note how the ratio decreases as progressively more damping is applied, indicating the greater stability of M-N.

The relatively large decrease in J-K as compared to the small decreases in H-I and M-N represents diminution of aftervibrations. H-I occurring after weak forces preceding large forces is less influenced by aftervibrations than I-J, which follows the relatively large H-I force. J-K is even more affected by aftervibrations because it follows two strong forces. K-L, a weak circulatory force following several stronger forces, appears to be affected most. The data suggest that J-K and K-L are largely results of aftervibrations, while I-J is also influenced but to a lesser degree. The relative increase in amplitude of M-N after damping most likely represents elimination of the effects of systolic aftervibrations.

D. *Body Frequency Changes.*—The body frequency of every subject was significantly altered by varying the amount of damping (Table IV). In general, body frequencies were slightly higher on the putty. Placing bags against the feet and shoulders increased the average body frequency from about 5 cycles per second to 7.5 cycles per second, while further increase of weights on the subject reduced the average body frequency to 5.6 cycles per second (Fig. 1). When weights were placed upon the body and not against the feet and shoulders, there was a slight increase in body frequency from 5.2 to 6 cycles per second. Placing

TABLE IV

SUBJECT	TABLE WITHOUT SANDBAGS	TABLE WITH SANDBAGS AGAINST SHOULDERS AND FEET	TABLE WITH BAGS AGAINST FEET AND SHOULDERS AND ON ABDOMEN AND THIGHS	PUTTY WITHOUT BAGS	PUTTY WITH BAGS AGAINST FEET AND SHOULDERS	PUTTY WITH BAGS AGAINST FEET AND SHOULDERS AND ON THIGHS AND ABDOMEN
BF	4.7	8.3	5.0	5.3	8.3	5.9
EO	3.6	6.2	5.5	4.5	8.1	5.0
MR	5.9	7.1	6.2	5.5	10.0	8.3
EEE	5.5	7.1	5.0	6.2	7.1	5.0
RS	4.5	5.5	4.5	5.0	6.2	5.5
AS	4.2	7.1	5.5	5.0	6.7	5.4
PN	5.0	8.3	6.2	5.0	6.2	5.5
JL	5.3	8.3	6.2	6.2	9.1	5.9
BH	4.5	7.1	5.5	5.0	9.1	6.2
BM	5.0	8.3	5.5	5.5	8.3	6.2
Averages	4.8	7.3	5.5	5.3	7.8	5.9

This table depicts the changes in body frequency in cycles per second on table and putty surfaces with varying degrees of damping. Note the slightly higher body frequencies in most subjects on the putty surface and the increase in body frequency when damping is applied to the subject's feet and shoulders. Note also how further addition of weights reduces body frequencies, suggesting overdamping. It is significant that the best records were obtained when the body frequency was highest.

bags against the feet and shoulders resulted in a further increase in body frequency to 7.6 cycles per second. If at this point more weights were placed on the subject, the body frequency decreased.

The best records were obtained when the body frequency was the highest, and the most notable improvement in tracings occurred in the subjects who initially displayed the lower body frequencies. When the body frequency was damped above 6 cycles per second, the records were nonoscillatory and influenced only minimally by aftervibrations. From our studies it would appear that it is possible to overdamp the subject. This was illustrated by a decrease in body frequency when extra weights were placed upon the subject who already had the feet and shoulders packed. Placing sandbags against the feet and shoulders produced a significant and desirable increase in body frequency in all of the subjects.

The coefficient of damping determined in nine subjects before packing the feet and shoulders with sandbags was found to vary markedly from subject to subject (Table V). The extremes ranged from 0.16 to 0.33, which helps to explain the marked variation in configuration of the ballistocardiogram between normal subjects.

TABLE V

	COEFFICIENT OF CRITICAL DAMPING		BODY FREQUENCY	
	NOT PACKED	PACKED	NOT PACKED	PACKED
BF	.16	.44	6.1	7.7
CF	.33	.38	5.3	7.1
BN	.36	.42	7.1	8.3
WF	.20	.35	6.7	8.3
BT	.27	.47	5.0	6.3
EO	.20	.35	5.3	7.1
JK	.17	.45	5.6	8.3
AU	.30	.45	4.8	7.1
BY	.18	.38	5.9	7.1

Packing the feet and shoulders produced an increase in the coefficient of critical damping and body frequencies in all subjects. Note the narrow range of variation in the coefficient of critical damping when feet and shoulders are packed with sandbags.

When the feet and shoulders of the subjects were packed with sandbags, the coefficient of damping increased in all subjects in varying degrees, but the entire group varied only between 0.35 and 0.47. This is a much more constant degree of damping than had been found prior to packing (Table IV).

Body frequency increased in all nine subjects when packed with sandbags (Table V). Body frequency for the group averaged 5.75 cycles per second before and 7.48 cycles per second after packing.

The combination of increased body frequency and increased damping obtained by placing sandbags against the feet and shoulders has apparently greatly reduced the amount of variation between normal subjects.

It thus seems imperative that some degree of damping be applied to the subjects if an accurate tracing is to be obtained. Apparently damping has a twofold effect: (1) diminution of aftervibrations, and (2) attainment of the optimal body frequencies to record circulatory forces in their proper perspective.

E. *Configuration Changes.*—When damping was applied, certain major changes were noted in the configuration of the ballistocardiograph. These consisted of slurring and shortening of the J-K downstroke, which often made identification of the K nadir difficult. A previously absent small K-L upstroke appeared about the time of the carotid incisural notch, followed by distinct M and N points (Fig. 1). In most subjects this K-L-M-N sequence had previously been a single wave labeled K-L. The damping in of this additional wave probably represents the diminution of the effects of aftervibrations and noncirculatory forces on the ballistocardiogram.

F. *Comparison of Pickup Areas.*—Inspection of Table VI reveals a lag in the H-I-J waves or early systolic forces of 0.04 second when recorded from the shin and compared to the head bellows record. When the bar-magnet device and bellows pickup are evaluated with a mechanical sine-wave generator, it is apparent that the bar magnet utilized in this study has an inherent lag of 0.02 second.

TABLE VI

TIMES MEASURED	HEAD BELLOWS		SHIN MAGNET	
	RANGE	AVERAGE	RANGE	AVERAGE
Q-G	.02–.08	0.059	.06–.11	0.085
Q-H	.08–.11	0.10	.11–.16	0.141
Q-I	.15–.17	0.164	.18–.22	0.203
Ce*-I	.04–.05	0.043	.08–.10	0.089
G-H	.03–.07	0.043	.05–.07	0.059
H-K	.21–.28	0.250	.19–.24	0.216
I-K	.16–.22	0.196	.14–.17	0.154
Q-K		0.360		0.357
I-J	.07–.11	0.093	.07–.09	0.08
J-K*		0.103		0.074
L-Cin†		0.008	.04–.03+	0.001
K-N	.16–.22	0.193	.20–.26	0.218
H-Ce*	.01–.08	0.03	.01–.06	0.029

*Ce = Onset of carotid ejection

†Cin = Incisura of the carotid pulse wave

This table displays the slight lag in the early diastolic waves recorded from the shins. This lag becomes of much less significance when the 0.2 second lag inherent in the bar magnet is considered.

Application of elastic stockings to the shins, as suggested by Smith, reduced the over-all lag in the shin recordings to 0.02 second, which we have found to be the inherent lag of the bar magnet device. It would appear that without elastic stockings on the shins a 0.02 second lag occurs that is probably due to skin slip-

page. This would seem to indicate that a simple coupling system such as a head bellows has more than a theoretical advantage over the double coupling system that is usually employed in shin recordings.

The lag in isometric contraction and in the early systolic waves, as recorded from the shins by the bar magnet, is no longer apparent when measured at the K nadir. The J-K downstroke is also noted to be slightly deeper in the shin tracings than in the head bellows records. The differences in time and configuration between the shin and head areas are extremely interesting, but conclusions as to their significance must await further studies with the newer instrument now being used by Smith. However, our studies indicate the head pickup to be a suitable recording site.

SUMMARY

1. With the exception of the K nadir, progressive damping did not alter time relationships of the ballistocardiogram with known events in the cardiac cycle. Alterations in the time intervals of the K point were impossible to assess because slurring of the J-K downstroke when damping was applied made the K nadir difficult to identify.

2. The I-J upstroke and especially the J-K downstroke amplitudes were reduced significantly with damping, while the H-I downstroke and the M-N upstroke amplitudes were only slightly diminished and relatively increased when compared to I-J and J-K. Possible reasons for these changes produced by damping are discussed.

3. Often a previously obscured over-all K-L sequence became visible when damping was applied. Occasionally this wave was notched. With damping the M point became clearly defined in all subjects.

4. Body frequencies increased maximally when weights and sandbags were placed against the feet, shoulders, axillae, and groins. Placing light weights on the subject gave a small initial increase in body frequency, but further increments of weight on the subject produced a decrease in body frequency. The relationship of body frequency to accurate ballistocardiographic recording is discussed.

5. Minor changes in configuration and a slight time lag were noted with the shin tracings, when compared to the head pickup area. The head pickup area appears to be suitable for recording ballistocardiograms from supine subjects on the putty surface.

6. Packing the feet and shoulders produced a significant increase in damping and, in addition, produced a more constant coefficient of damping than was present prior to packing.

7. If damping is applied to subjects on the table surface, many but not all subjects will display a ballistocardiogram quite similar to the ballistocardiogram recorded from the putty surface.

REFERENCES

1. Walker, Rhett P., Reeves, T. J., Willis, Kathryn, Christianson, Lynn, Pierce, J. Rush, and Kahn, Donald: The Effect of Surfaces and Recording Technique on the Direct Ballistocardiogram, AM. HEART J. 46:161, 1953.
2. Smith, J. E.: A Calibrated Bar Magnet Velocity Meter for Use in Ballistocardiography, AM. HEART J. 44:872, 1952.
3. Scarborough, W. R.: Personal communication.

STUDIES OF PULMONARY HYPERTENSION. VI.

Pulmonary "Capillary" Pressure In Various Cardiopulmonary Diseases At Rest And Under Stress

Paul N. Yu, M.D., Frank W. Lovejoy, Jr., M.D., Howard A. Joos, M.D., Robert E. Nye, Jr., M.D., David C. Beatty, M.D., M.R.C.P., and John H. Simpson, M.D., M.R.C.P.

Rochester, N. Y.

With the Technical Assistance of Caroline Gouverneur and S. John Vernarelli

MANY reports have described pulmonary "capillary" pressure, or pulmonary artery wedge pressure in normal subjects[1-3] and in patients with mitral stenosis,[4-17] chronic pulmonary disease,[18-20] constrictive pericarditis,[21-23] left ventricular failure,[24,25] and various types of congenital heart disease.[26-31] The response of pulmonary "capillary" pressure to exercise,[8,11,23,24,26,32,33] epinephrine[34] and norepinephrine[35] injections, rapid saline infusion,[36] Valsalva's experiment,[37] and acute hypoxia[38,39] has also been reported. Recently, Lenègre and associates[40] have studied pulmonary "capillary" pressure in 134 cases including normal subjects and patients with cardiopulmonary diseases. They found that the pulmonary "capillary" pressure was normal at rest and during exertion in patients with chronic pulmonary disease and congenital heart disease. On the other hand, the pulmonary "capillary" pressure was elevated in every case where there was interference with emptying of the pulmonary veins: severe mitral stenosis, left ventricular failure, or constrictive pericarditis. In such cases exertion or anxiety increased the pulmonary "capillary" pressure. In our laboratory we have studied the pulmonary "capillary" pressure in 150 patients with various cardiopulmonary diseases. It is the purpose of this article (a) to report the pulmonary "capillary" pressure and pulmonary artery-pulmonary "capillary" pressure gradient in these patients, (b) to describe the changes in the pulmonary "capillary" pressure in certain patients under stress, and (c) to delineate some of the features of precapillary and postcapillary pulmonary hypertension.

From the Chest Laboratory, Departments of Medicine and Pediatrics, University of Rochester School of Medicine and Dentistry, and Medical and Pediatric Clinics, Strong Memorial and Rochester Municipal Hospitals, Rochester, N. Y.

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CLINICAL MATERIAL AND METHOD

One hundred fifty patients with various cardiopulmonary diseases were studied. The diagnosis in these patients is given in Tables I, II, and III.*

Cardiac catheterization was performed on each patient two or three hours after a light breakfast, according to a modification of the method of Cournand and Ranges.[41] Premedication was given to certain children in order to alleviate anxiety and apprehension; in adults, with a few exceptions, no premedication was administered. A single or double lumen catheter was employed. The catheter was first advanced as far as possible into a distal radicle of one of the pulmonary arteries in order to occlude its lumen. Pulmonary "capillary" pressure was recorded by the method of Hellems and associates.[1] The criteria for satisfactory pulmonary "capillary" pressure were similar to those described by Fowler and associates[35]: (a) peripheral location and no oscillation of the catheter tip in the lung by fluoroscopy, (b) the nature of the pressure curve ("a" and "v" waves in most patients with sinus rhythm, and configuration and magnitude different from that of the pulmonary artery pattern), and (c) aspiration of blood specimens fully saturated with oxygen from the wedged tip. No pulmonary "capillary" blood could be obtained in a number of patients, however, particularly those with chronic pulmonary disease. In some other patients the blood sample withdrawn was desaturated, although the catheter was in the wedged position and the pattern of pulmonary "capillary" pressure was typical.

When the double lumen catheter was used, the pulmonary "capillary" and the pulmonary artery pressures were recorded simultaneously. When a single lumen catheter was used, the pulmonary "capillary" pressure was measured first. After appropriate studies the catheter was slowly withdrawn until its tip was just distal to the bifurcation of the pulmonary artery.

During an exercise period, the recumbent patient performed cycling movements of both legs until compelled to stop from fatigue, a period varying from 1 to 3 minutes. To observe the effects of acute hypoxia the inspired gases were varied using a three-way stop-cock from room air to a mixture of 12 per cent oxygen in nitrogen for 15 minutes or more. In patients with normal pulmonary "capillary" pressure during the control observation, when a double lumen catheter was used, pulmonary artery and pulmonary "capillary" pressures were recorded simultaneously before, during, and after the period of exercise or of breathing low oxygen. A single lumen catheter was sometimes used for the exercise studies. The tip was first wedged throughout the experiment after which the entire procedure was repeated with the catheter tip free in the pulmonary artery. When the pulmonary "capillary" pressure was initially elevated, the procedure was altered in order not to provoke pulmonary edema. With both single and double lumen catheters an initial pulmonary "capillary" reading was obtained after which the tip was withdrawn to the pulmonary artery where

*The abbreviations used are as follows: PCm for pulmonary "capillary" mean pressure, PAm—PCm gradient for pulmonary artery—pulmonary "capillary" mean pressure gradient, PAm for pulmonary artery mean pressure, and RAm for right atrial mean pressure.

The upper limit of the normal PCm, PAm—PCm gradient, and PAm is, respectively, 12, 10, and 20 mm. Hg.

it remained free during the exercise or hypoxic period. Towards the end of the hypoxic period or immediately after exercise, it was advanced again to the wedged position and a pulmonary "capillary" pressure recorded. During the remainder of the recovery period, the tip was withdrawn to the pulmonary artery and pressures were recorded here at one-minute intervals. On several occasions, in order to be sure that an immediate rise in pulmonary artery pressure had not been missed while the pulmonary "capillary" pressure was being obtained, exercise was repeated with the tip in the pulmonary artery throughout.

Pressures were recorded by means of a Statham strain gauge connected to a carrier wave amplifier in a Sanborn multi-channel direct-writing oscillograph. The electrocardiogram and pneumocardiogram were recorded simultaneously. The pressure records were calibrated with a mercury manometer. Systolic and diastolic pressures were measured for at least three respiratory cycles and average values calculated. Mean pressures were measured by planimetric integration of the pressure tracings during at least two respiratory cycles. The arbitrary zero point of all pressures with the patient in a recumbent position was 6.5 cm. below the angle of Louis for adults and the midaxillary line for children.

RESULTS

A. *Pulmonary "Capillary" Pressure at Rest.*—The patients studied may be grouped according to the magnitude of their PAm and PCm: (a) Group I: Elevated PAm and normal PCm (precapillary pulmonary hypertension), (b) Group II: Elevated PAm and PCm (postcapillary pulmonary hypertension), (c) Group III: Normal PAm and PCm (no pulmonary hypertension), and (d) Group IV: A borderline group of patients with minimal elevation of PAm or PCm or both, who do not clearly belong in Group I or Group II. The diagnoses and the number of patients in each group are given in Tables I, II, and III.

Group I: *Precapillary pulmonary hypertension* (*Table I*): Sixteen of the twenty-eight cases of chronic pulmonary disease fell into this group, PAm ranging from 21 to 49 mm. Hg with an average of 29 mm. Hg. The PCm was 12 mm. Hg or less in all but one case, the average being 6 mm. Hg. The PAm—PCm gradient was elevated in all, ranging from 14 to 39 mm. Hg with an average of 23 mm. Hg. Five of the patients with congenital heart disease had significant pulmonary hypertension with increased PAm—PCm gradients and normal or borderline PCm. These included two of five cases of patency of the ductus arteriosus,* one of three cases of interventricular septal defect, and one case each of Eisenmenger's complex and Taussig's syndrome. In addition, three cases of primary pulmonary hypertension (one proved at autopsy and one associated with dilatation of the pulmonary artery) had normal PCm.

Group II: *Postcapillary pulmonary hypertension* (*Table II*): Pulmonary hypertension was found in forty-one out of forty-five cases of predominant mitral stenosis studied preoperatively, of which two are relegated to Group IV. The highest PAm was 75 mm. Hg and the average 43 mm. Hg. The highest

*This high incidence is attributable to the fact that few patients with classical patency of the ductus are subjected to cardiac catheterization in our clinic.

TABLE I. GROUP I: PATIENTS WITH PRECAPILLARY PULMONARY HYPERTENSION

DIAGNOSIS	NO. PATIENTS	PRESSURES IN MM. HG		
		PA_m	PC_m	$PA_m—PC_m$ GRADIENT
a. Chronic pulmonary disease	16	21	3	18
		22	4	18
		22	7	15
		22	8	14
		24	6	18
		26	−1	27
		26	2	24
		27	2	25
		27	7	20
		28	9	19
		29	1	28
		29	8	21
		31	9	22
		37	13	24
		38	7	31
		49	10	39
b. Congenital heart disease				
(1) Eisenmenger's complex	1	83	13	70
(2) Taussig syndrome	1	70	5	65
(3) Patent ductus arteriosus	2	70	9	70
(4) Interventricular septal defect	1	30	14	16
c. Primary pulmonary hypertension				
1 proved at autopsy		46	11	35
1 with dilated pulmonary artery		30	9	21
1 suspected		63	3	60

PCm was 39 mm. Hg and the average 28 mm. Hg. The PAm—PCm gradient was elevated in two-thirds of this group. Usually there was a good correlation between PCm and PAm—PCm gradient; the higher the PCm, the higher the gradient. However, there were exceptions: in two cases the PCm was 30 mm. Hg or higher, yet the gradient was only 3 and 4 mm. Hg, respectively.

Elevated PAm and PCm were found in seven of eight cases of mitral stenosis following mitral valvuloplasty. In one case with predominant mitral insufficiency, both PAm and PCm were considerably above normal. In addition, both were elevated in each of the following: Lutembacher's syndrome, pericardial constriction, and probable subendocardial fibroelastosis.

Group III: *No Pulmonary Hypertension* (*Table III*): This group included most of the cases of congenital heart disease, aortic and tricuspid valve disease, hypertensive cardiovascular disease in the absence of failure, and twelve of twenty-eight cases of chronic pulmonary disease.

Group IV: *Borderline Pulmonary Hypertension* (*Table IV*): Two patients with mitral stenosis had elevation of PCm with normal PAm, suggesting the imminence of pulmonary hypertension. Two other patients with mitral stenosis

TABLE II. GROUP II: PATIENTS WITH POSTCAPILLARY PULMONARY HYPERTENSION

DIAGNOSIS	NO. PATIENTS	PRESSURES IN MM. HG		
		PA_m	PC_m	PA_m—PC_m GRADIENT
a. Mitral stenosis				
(1) Preoperative	39	23	16	7
		24	16	8
		25	19	6
		28	22	6
		28	24	4
		29	20	9
		29	22	7
		31	22	9
		31	24	7
		33	22	11
		33	26	7
		33	30	3
		35	25	10
		38	27	11
		40	26	14
		41	21	20
		41	29	12
		41	29	12
		41	29	12
		42	27	15
		42	38	4
		47	21	26
		47	23	24
		49	30	19
		40	32	17
		50	30	20
		51	31	20
		51	36	15
		53	28	25
		53	32	21
		53	39	14
		54	25	29
		54	30	24
		55	39	16
		56	31	25
		58	34	24
		58	38	20
		71	36	35
		75	34	41
a. Mitral stenosis				
(2) Postoperative	7	21	15	6
		27	17	10
		32	17	15
		32	26	6
		36	26	10
		47	15	32
		51	23	28
b. Other conditions				
(1) Lutembacher syndrome	1	28	17	11
(2) Mitral insufficiency	1	50	30	20
(3) Left ventricular failure	2	44	24	20
		23	16	7
(4) Pericardial constriction	1	27	22	5
(5) Probable subendocardial elastofibrosis	1	42	24	18

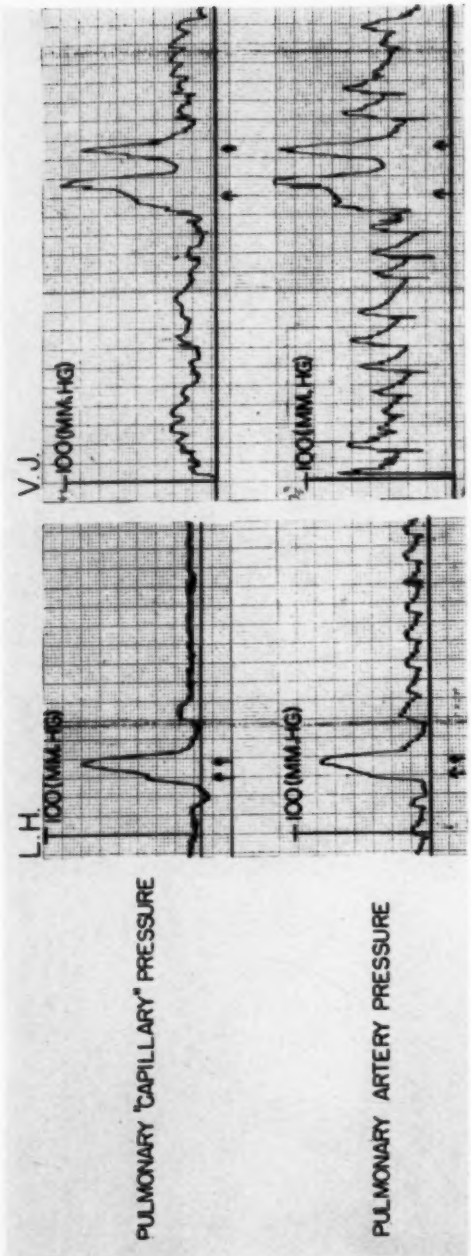

Fig. 1.—Response of pulmonary artery and pulmonary "capillary" pressures to maximal cough in two patients. (See text for explanation.)

TABLE III. GROUP III: PATIENTS WITH NO PULMONARY HYPERTENSION

DIAGNOSIS	NO. PATIENTS
a. Congenital heart disease	
(1) Uncomplicated pulmonary stenosis	
Preoperative	14
Postoperative	1
(2) Pulmonary stenosis associated with other cardiac lesions	2
(3) Patent ductus arteriosus	
Preoperative	3
Postoperative	1
(4) Interatrial septal defect	4
(5) Interventricular septal defect	2
(6) Idiopathic dilatation of the pulmonary artery	2
(7) Coarctation of aorta	1
(8) Ebstein's disease	1
(9) Anomalous pulmonary venous drainage	1
b. Chronic pulmonary disease	12
c. Rheumatic heart disease	
(1) Mitral stenosis	
Preoperative	2
Postoperative	1
(2) Mitral insufficiency	1
(3) Aortic valvular lesions	5
(4) Tricuspid stenosis	1
d. Miscellaneous conditions	
(1) Hypertensive cardiovascular disease	2
(2) Myxedema	3
(3) Constrictive pericarditis	
(a) Predominant right side	1
(b) Postoperative	1
(4) Unknown diagnosis	7

and two with interatrial septal defect had minimal elevation of both pressures with a high normal or minimally elevated PAm—PCm gradient and could not be classified with certainty in the previously mentioned groups.

TABLE IV. PATIENTS WITH BORDERLINE PULMONARY HYPERTENSION

DIAGNOSIS	NO. PATIENTS	PRESSURES IN MM. HG		
		PA_m	PC_m	PA_m—PC_m GRADIENT
a. Mitral stenosis	4	24	13	11
		24	14	10
		19	17	2
		18	14	4
b. Interatrial septal defect	2	24	13	11
		22	13	9

B. *Pulmonary "Capillary" Pressure During Stress.*—

1. *Cough*: The response of pulmonary artery and "capillary" pressures to cough was studied in fifty patients (Fig. 1). With maximal cough both pres-

sures rose to a high level, often exceeding 100 mm. Hg. In some patients similar increase in the right atrial pressure was also recorded during cough. In one patient with chronic pulmonary disease the pulmonary artery systolic pressure rose to 240 mm. Hg, and pulmonary "capillary" pressure exceeded 120 mm. Hg. In general, the rise of pulmonary "capillary" pressure was most marked in patients with chronic pulmonary disease and mitral stenosis, and less in patients with congenital heart disease. This may be in part an artifact related to the age of the patients and their cooperation.

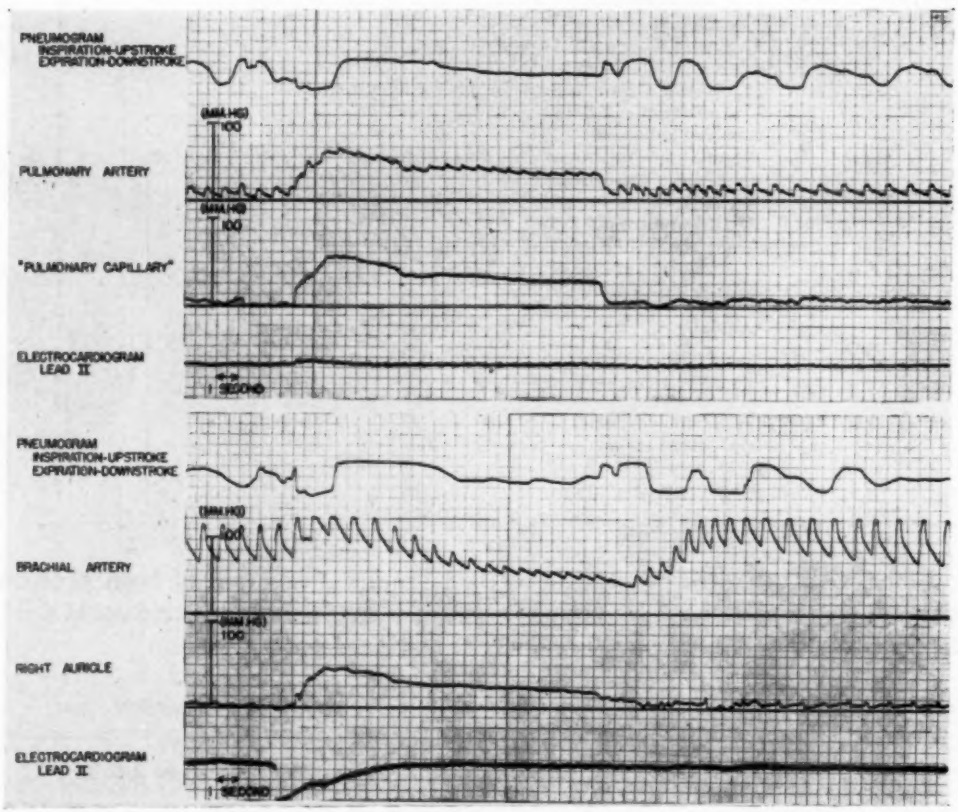

Fig. 2.—Response of pulmonary artery, pulmonary "capillary," brachial artery, and right atrial pressures in a patient (L.H.) to Valsalva maneuver. Note that the changes in the pulmonary "capillary" and right atrial pressures are similar.

2. *Valsalva maneuver*: The response of pulmonary artery and "capillary" pressures to the Valsalva maneuver was recorded in forty patients (Fig. 2). There is no noticeable difference between the response of patients with normal and elevated PCm. In general the rise of the pulmonary artery pressure is greater than that of the pulmonary "capillary" pressure. In one patient with proved primary pulmonary hypertension, PAm rose to 95 mm. Hg and PCm only to 36 mm. Hg during the initial phase of the Valsalva maneuver. Since the intrathoracic pressure was not measured during the maneuver, it is not possible to quantitate the magnitude of the response. During the initial phase

there is usually a significant and parallel rise of both pulmonary artery and "capillary" pressures to a level as high as 100 mm. Hg. Thereafter, the pressures are maintained at about twice the control value. After the Valsalva maneuver the pressures may fall below the resting level. This is followed by a rapid rise to the control level or by an overshoot. The pulmonary artery or "capillary" pulse pressure may be variably narrowed. In some patients the response of the right atrial pressure to the Valsalva maneuver was similar to that seen in either pulmonary artery or pulmonary "capillary" pressure.

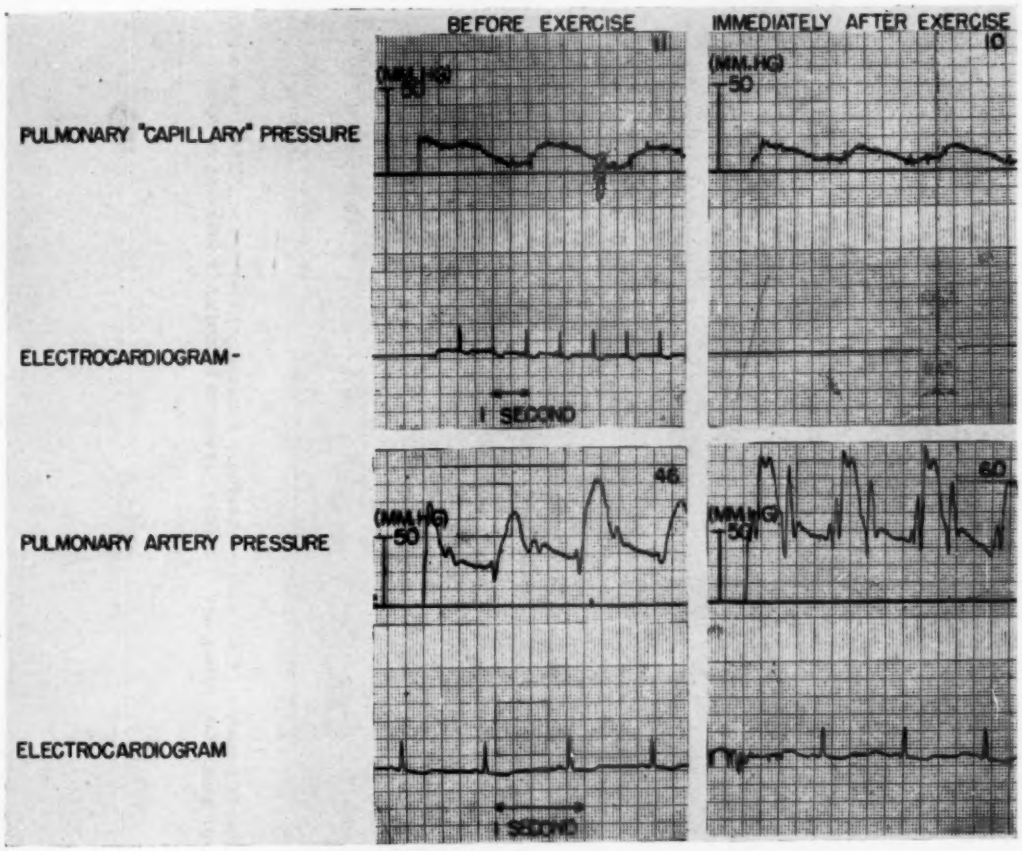

Fig. 3.—Exercise response in a patient (H.F.) with precapillary pulmonary hypertension. Note the rise in pulmonary artery pressure and no significant change in pulmonary "capillary" pressure immediately following exercise. In this and subsequent figures the mean pressure in mm. Hg is given in the upper right corner of each tracing.

3. *Exercise*: The response of PAm and PCm to exercise differed in the three groups. In patients with precapillary pulmonary hypertension there was usually a rise in the PAm but little change in the PCm (Fig. 3). In patients with postcapillary pulmonary hypertension, both PAm and PCm invariably rose to a high level (Fig. 4). Two patients whose PCm exceeded 35 mm. Hg following exercise developed pulmonary edema. In patients with normal pressures in the pulmonary circuit there was usually no significant change in either measurement following exercise.

4. *Acute hypoxia*: We have observed the effect of acute hypoxia on the

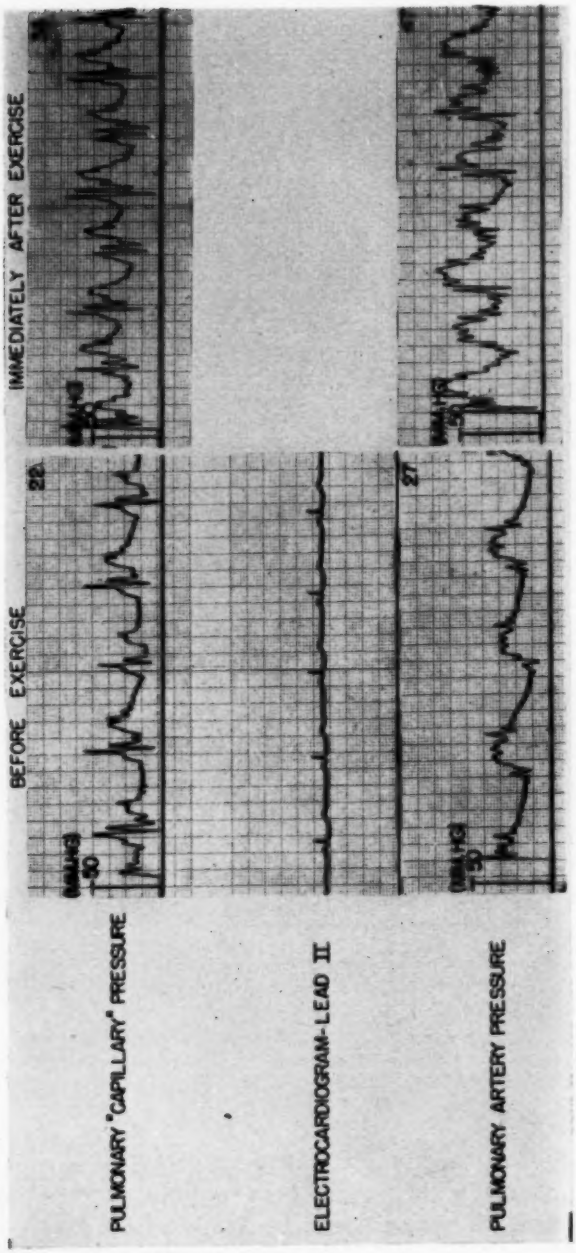

Fig. 4.—Exercise response in a patient (A.E.) with postcapillary pulmonary hypertension. There was a significant rise in both pulmonary artery and "capillary" pressures immediately following exercise.

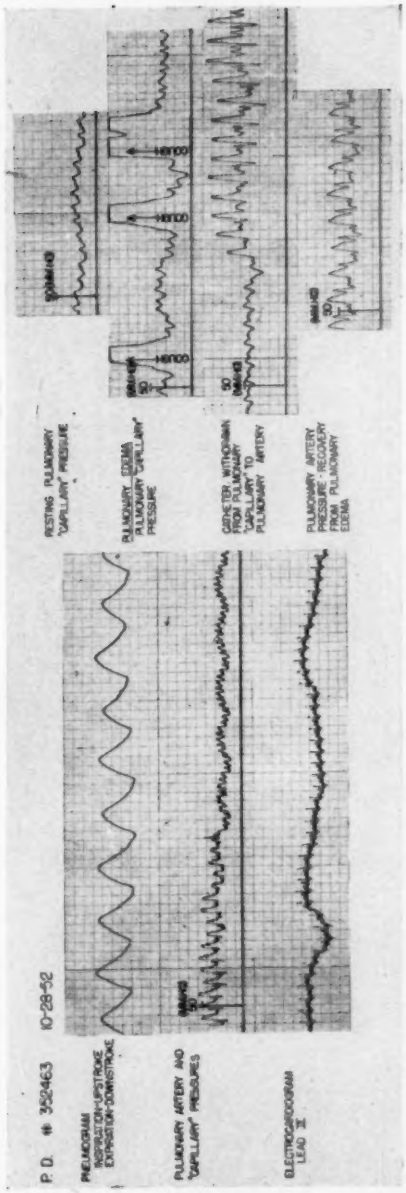

Fig. 5.—Development of pulmonary edema in a patient with postcapillary pulmonary hypertension (mitral stenosis) after the tip of the catheter was in the wedged position for more than fifteen minutes. On the left: continuous recording of the pressure in the pulmonary circuit with simultaneous pneumogram and electrocardiogram as the catheter was advanced from the proximal portion of the pulmonary artery to the wedged position. On the right: pressures recorded during development of, and recovery from, pulmonary edema.

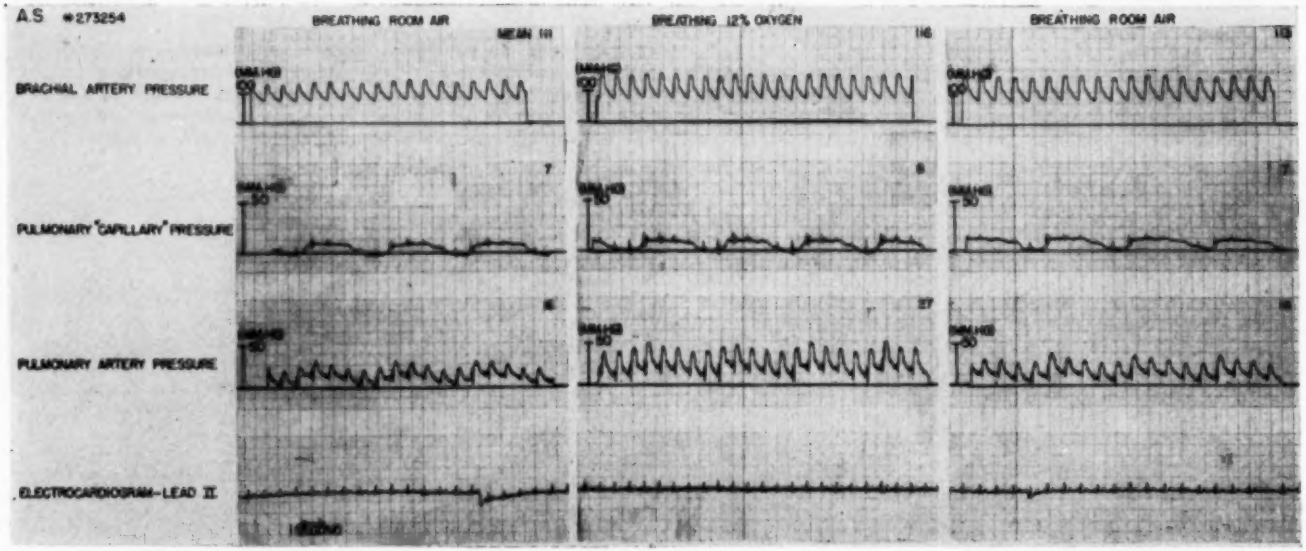

Fig. 6.—Circulatory effects of hypoxia in a patient with pulmonary emphysema. Note the significant rise in pulmonary artery pressure without change in pulmonary "capillary" and brachial artery pressures during the period of breathing 12 per cent oxygen in nitrogen.

PCm and PAm in eighteen patients with mitral stenosis, four patients with chronic pulmonary disease, one patient with predominant tricuspid stenosis, and one patient with no cardiopulmonary disease. In sixteen of eighteen patients with mitral stenosis the PAm was increased more than 5 mm. Hg during the period of low oxygen inhalation (Fig. 5). The two exceptional patients had had a previous successful mitral valvuloplasty. The PCm was measured during the period of hypoxia in only three patients. It rose significantly in two and did not change in the third. The PCm at rest was elevated in the first two patients and was normal in the third.

In patients with chronic pulmonary disease, there was a significant rise in the PAm but no change in the PCm following acute hypoxia (Fig. 6). In one patient with predominant tricuspid stenosis and in another patient with no cardiopulmonary disease, there was no change in either PAm or PCm during the period of acute hypoxia.

DISCUSSION

Precapillary pulmonary hypertension usually occurs in patients with increased pulmonary vascular resistance: namely, most cases of chronic pulmonary disease, a minority of cases of cyanotic and late cyanotic types of congenital heart disease, and primary pulmonary hypertension. Postcapillary pulmonary hypertension almost always occurs in patients with impaired blood flow through the left ventricle due to mitral stenosis or insufficiency or both, left ventricular failure, constrictive pericarditis involving the left side of the heart, and probably subendocardial fibroelastosis. Normal pulmonary artery pressure is found in patients in whom there is no obstruction to blood flow through the pulmonary vascular bed or into the left ventricle. This occurs in a majority of cases of acyanotic and late cyanotic types of congenital heart disease with no abnormality of the left atrium or ventricle, and in some cases of chronic pulmonary disease, hypertensive cardiovascular disease, and chronic aortic valvular disease without failure. The PAm—PCm gradient in most patients with congenital heart disease is normal.

We feel strongly that the recording of the pulmonary "capillary" pressure is helpful in differentiating the nature of many cases of pulmonary hypertension. If the pulmonary artery pressure is moderately or markedly elevated and the pulmonary "capillary" pressure is normal, one can exclude an abnormality in the left side of the heart as a dominant cause of the pulmonary hypertension. Therefore, in such a case the pulmonary hypertension is precapillary in nature and the possibilities of chronic pulmonary disease or congenital heart disease should be foremost. On the other hand, if both pulmonary artery and "capillary" pressures are high, the responsible mechanism is probably in the left heart and the differential diagnosis should include mitral stenosis, left ventricular failure, and constrictive pericarditis.

Many investigators have demonstrated that the mean pulmonary "capillary" or pulmonary artery wedge pressure is a reliable index of the mean pulmonary venous and left atrial pressures, either in a closed or open chest.[12,13,37,42,43] However, there is no agreement regarding the fidelity with which the phasic changes in the pulmonary "capillary" reflect those of left atrial pressure.[44] With postcapillary pulmonary hypertension of lesser severity the increased pulmonary

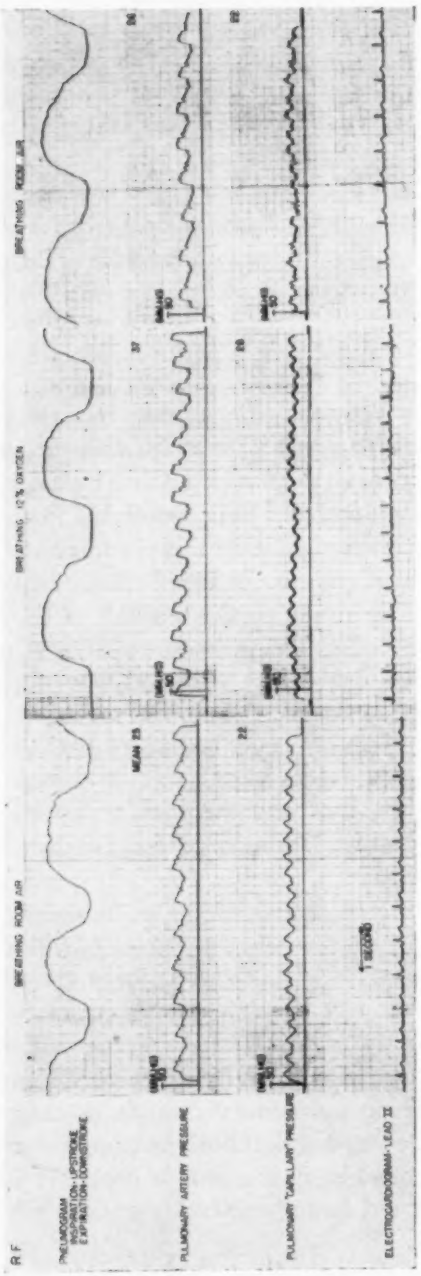

Fig. 7.—Circulatory effects of hypoxia in a patient with mitral stenosis. There was a distinct rise in the pulmonary artery pressure with a less significant rise in the pulmonary "capillary" pressure.

artery pressure is passive, resulting from a rise in the left atrial, pulmonary venous, and "capillary" pressures. In more severe examples, organic changes or functional vasoconstriction or both may be largely responsible for further increase in the pulmonary artery pressure, and there is a tendency for the pulmonary "capillary" pressure to become fixed at or slightly below the edema level (25 to 35 mm. Hg).[5,8,10] On the other hand, with precapillary pulmonary hypertension, the pulmonary artery pressure may be extremely high, yet the pulmonary "capillary" pressure almost always remains normal. In most such cases in the present series the resting right atrial mean pressure was also within normal limits. Therefore, the pulmonary hypertension cannot be explained by increased left atrial or mean intrathoracic pressure. The lesion is predominantly in the pulmonary arterioles which may exhibit pronounced irreversible organic changes or reversible functional vasoconstriction or both.

The relationship between the PAm and the PCm and that between the PAm and PAm—PCm gradient in sixteen cases of chronic pulmonary disease with pulmonary hypertension and in forty-six cases of mitral stenosis (pre- and postoperative) is shown in Figs. 8 and 9. In chronic pulmonary disease the PAm is not related to PCm ($r = 0.490$), but is directly proportional to PAm—PCm gradient ($r = 0.858$), whereas in mitral stenosis a good correlation is obtained between PAm and both PCm and PAm—PCm gradient, ($r = 0.720$ and 0.860, respectively).

Clinically, there is a striking difference in patients with the two types of pulmonary hypertension. Those with postcapillary pulmonary hypertension frequently show signs of pulmonary edema or congestion. These are rare manifestations in the group with precapillary pulmonary hypertension.

In a previous study of eighteen cases of chronic pulmonary disease with and without pulmonary hypertension, no significant correlation was found between PCm and the following: total pulmonary resistance, pulmonary artery mean and diastolic pressures, and cardiac index.[20] The lack of significant correlation between a normal PCm and an elevated pulmonary artery systolic or diastolic pressure in most patients clearly indicates the precapillary nature of the pulmonary hypertension. On the other hand, in a previous report we have shown in forty-three cases of mitral stenosis that there was a significant correlation of PCm with pulmonary artery mean and diastolic pressures, total pulmonary resistance, and cardiac index.[17]

The pulmonary "capillary" pressure pattern in disease varies greatly. In most cases with sinus rhythm, however, the "a" and "v" waves are demonstrable. In patients with very low pulmonary "capillary" pressure there may be no identifiable deflections, although respiratory variation is usually observed. During inspiration the pressure falls and during expiration it rises.

A high peaked "v" wave in the pulmonary capillary pressure tracing has been suggested as an indication of mitral regurgitation but is not a reliable sign in our experience. In two patients the pulmonary "capillary" pressure tracing did not suggest mitral regurgitation and yet at operation a definite regurgitant jet in the left atrium was felt. In two others the possibility of mitral insufficiency was suggested by a systolic peak in the pulmonary "capillary" pressure tracing, although a systolic murmur was absent and at operation no regurgitant jet was palpable.

Both PAm and PCm rise considerably during cough. This increase in pressure is presumably due to elevation of the intrathoracic pressure. When a double lumen catheter is used, in most cases a very small PAm—PCm gradient was noted during cough. In one patient with chronic pulmonary disease, however, the PAm rose to 240 mm. Hg and the PCm to 120 mm. Hg with cough.

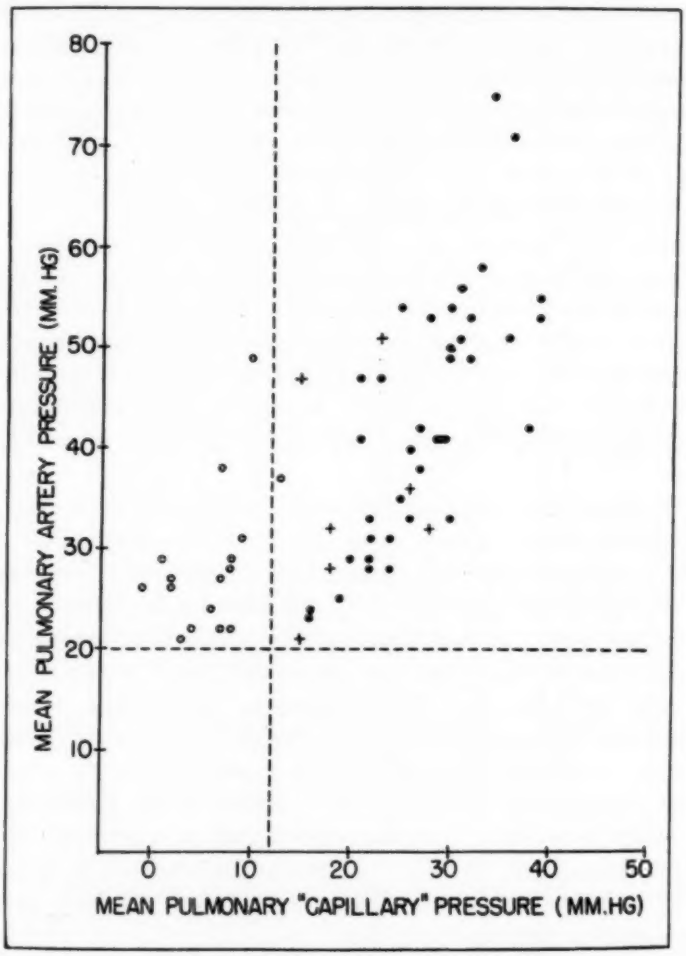

Fig. 8.—Correlation between the mean pulmonary artery and pulmonary "capillary" pressures in sixteen patients with chronic pulmonary disease and 46 patients with mitral stenosis (pre- and postoperative). Note: (a) normal PCm pressure in all but one case of chronic pulmonary disease and elevated PCm in all cases of mitral stenosis, and (b) absence of correlation between PAm and PCm in chronic pulmonary disease ($r = 0.490$, $p > 0.05$) and significant positive correlation between these two in mitral stenosis ($r = 0.858$, $p < 0.01$). In this and the subsequent figure the hollow circle represents chronic pulmonary disease, the solid circle preoperative mitral stenosis, and the cross postoperative mitral stenosis.

He had had frequent attacks of syncope following violent paroxysms of cough prior to the study. It is postulated that because of the excessive increase in intrathoracic pressure during cough the pulmonary circulation was blocked and return to the left ventricle markedly diminished, resulting in cerebral anoxia.

In some patients persistent cough developed when the catheter was wedged

for more than fifteen minutes in the distal pulmonary artery. This may indicate the onset of incipient pulmonary edema and the catheter should be withdrawn to the proximal portion. This phenomenon occurs most frequently in patients with a high resting PCm, e.g., mitral stenosis (Fig. 7), but has also been observed in patients with predominant aortic insufficiency, tricuspid stenosis, and mild mitral insufficiency. In the latter examples the resting PCm was normal. How-

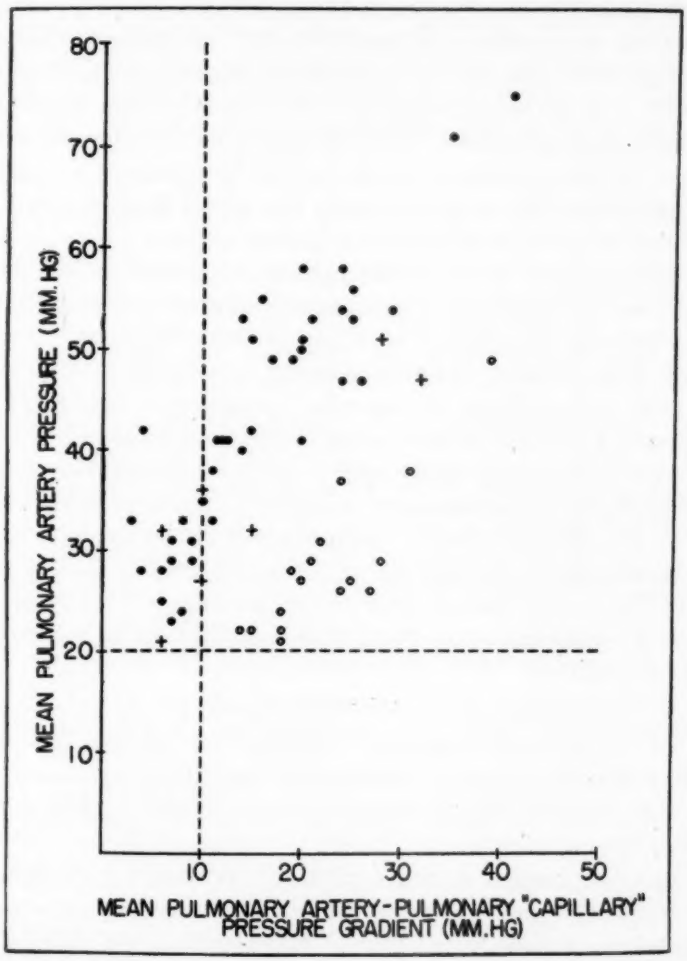

Fig. 9.—Correlation between the mean pulmonary artery pressure and the mean pulmonary artery —pulmonary "capillary" pressure gradient in sixteen patients with chronic pulmonary disease, and forty-six patients with mitral stenosis (pre- and postoperative). Note a significant positive correlation between the PAm and PAm—PCm gradient in both conditions (r = 0.720 and 0.860, respectively, p = < 0.01).

ever, we have not seen pulmonary edema develop in patients with chronic pulmonary disease, even after the catheter had been wedged for more than two hours. The reason is unknown.

The response of the pulmonary artery and "capillary" pressures to the Valsalva maneuver was quite uniform in most cases. In a number of patients the rise of the mean right atrial and right ventricular end-diastolic pressures was similar to that in the pulmonary circuit. Recently Björk and his associates[37]

have reported a parallel response in pulmonary "capillary" and left atrial pressures to the Valsalva maneuver in patients with mitral stenosis.

The effect of exercise on the pulmonary artery and "capillary" pressures in normal individuals has been described by Dexter and associates.[32] With moderate exercise there was no significant change in either PAm or PCm. The pressure responses to exercise in patients with obstruction to left heart flow, e.g., mitral stenosis, left ventricular failure, and constrictive pericarditis have been described by various investigators.[8,11,23,24,33] In these patients both PAm and PCm increase following exercise. In the group with precapillary pulmonary hypertension there may be a considerable rise in the PAm with no change in PCm. Here the increased blood flow through a restricted pulmonary vascular bed provokes a rise in pulmonary artery but not in pulmonary "capillary" pressure. Thus, with exercise, obstruction to the blood flow causes a rise in the pressure in the chamber or vessel proximal to obstruction.

Acute hypoxia usually increases the pulmonary artery but not the pulmonary "capillary" pressure in patients with chronic pulmonary disease and in normal subjects.[38,39] The rise in pulmonary artery pressure may be due to functional constriction of the pulmonary arterioles or may be secondary to increased pulmonary blood flow with fixation of vascular resistance. The small number of patients with mitral stenosis studied in our laboratory have nearly always shown a significant rise in the pulmonary artery pressure during the period of acute hypoxia. The response of pulmonary "capillary" pressure is variable, but with moderate or severe mitral stenosis a significant rise may be expected. This may be due to an augmented blood flow. Similar studies were made by Doyle and associates[39] in two patients with mitral stenosis. The PCm increased in one patient and decreased in another, although there was a significant rise in the PAm in both patients.

SUMMARY

Studies of pulmonary "capillary" pressure or pulmonary artery wedge pressure and pulmonary artery—pulmonary "capillary" pressure gradient are reported in 150 patients with cardiopulmonary disease, including the effects of acute stress in certain patients.

Sixteen of twenty-eight patients with chronic pulmonary disease, five patients with congenital heart disease, and three cases of primary pulmonary hypertension had precapillary pulmonary hypertension and an elevated PAm—PCm gradient.

Postcapillary pulmonary hypertension occurred in forty-one of forty-five cases of predominant mitral stenosis with elevation of the PAm—PCm gradient in two-thirds and with correlation, in general, between the magnitude of the PCm and the PAm—PCm gradient. Postcapillary pulmonary hypertension was observed in seven of eight patients after mitral valvuloplasty and in various other examples of impaired left heart flow.

Most cases of congenital heart disease, tricuspid and aortic valve disease, hypertension without failure, and twelve of twenty-eight patients with chronic pulmonary disease had a normal PAm and PCm.

Maximal cough caused a sharp rise in PAm and PCm, the latter more marked with chronic pulmonary disease and mitral stenosis.

The Valsalva maneuver usually caused a rise in PAm greater than that of PCm.

Exercise caused a rise in PAm and little change in PCm in patients with precapillary pulmonary hypertension. In the postcapillary type both PAm and PCm rose significantly with exercise.

Acute hypoxia elevated the PAm in unoperated patients with mitral stenosis and elevated the PCm in two of three patients. With chronic pulmonary disease hypoxia elevated the PAm without effect on the PCm.

The differentiation of pre- and postcapillary pulmonary hypertension is discussed, and the significance of the pulmonary "capillary" pressure pattern is reviewed. The effects of various acute stresses and their interpretation are discussed.

We wish to express our thanks to Mrs. Julia Gooding for her help in preparing the manuscript.

REFERENCES

1. Hellems, H. K., Haynes, F. W., and Dexter, L.: Pulmonary "Capillary" Pressure in Man, J. Appl. Physiol. **2**:24, 1949.
2. Lagerlöf, H., and Werkö, L.: Studies on the Circulation of Blood in Man. VI. The Pulmonary Capillary Venous Pressure in Man, Scandinav. J. Clin. & Lab. Invest. **1**:147, 1949.
3. Fowler, N. O., Westcott, R. N., and Scott, R. C.: Normal pressure in the Right Heart and Pulmonary Artery, Am. Heart J. **46**:264, 1954.
4. Dexter, L., Dow, J. W., Haynes, F. W., Whittenberger, J. L., Ferris, R. G., Goodale, W. T., and Hellems, H. R.: Studies of the Pulmonary Circulation at Rest. Normal Variation and the Inter-Relations Between Increased Pulmonary Blood Flow, Elevated Pulmonary Arterial Pressure and High Pulmonary "Capillary" Pressures, J. Clin. Invest. **29**:602, 1950.
5. Gorlin, R., Haynes, F. W., Goodale, W. T., Sawyer, C. G., Dow, J. W., and Dexter, L.: Studies of the Circulatory Dynamics in Mitral Stenosis. II. Altered Dynamics at Rest, Am. Heart J. **41**:30, 1951.
6. Gorlin, R., Lewis, B. M., Haynes, F. W., Spiegl, R. J., and Dexter, L.: Factors Regulating Pulmonary "Capillary" Pressure in Mitral Stenosis. IV., Am. Heart J. **41**:834, 1951.
7. Draper, A., Heimbecker, R., Daley, R., Caroll, D., Mudd, G., Wells, R., Falholt, W., Andrus, E. C., and Bing, R. J.: Physiologic Studies in Mitral Valvular Disease, Circulation **3**:531, 1951.
8. Lukas, D. S., and Dotter, C. T.: Modification of Pulmonary Circulation in Mitral Stenosis, Am. J. Med. **12**:639, 1952.
9. Miller, G., Goldberg, H., Elisberg, E. I., Snider, G. L., Toor, M., and Katz, L. N.: Cardiopulmonary Studies in Patients With Mitral Stenosis. I. Cardiovascular Dynamics, J. Lab. & Clin. Med. **40**:390, 1952.
10. Araujo, J., and Lukas, D. S.: Interrelationships Among Pulmonary "Capillary" Pressure, Blood Flow and Valve Size in Mitral Stenosis. The Limited Regulatory Effects of the Pulmonary Vascular Resistance, J. Clin. Invest. **31**:1082, 1952.
11. Eliasch, H., Wade, G., and Werko, L.: The Effects of Work on the Pulmonary Circulation in Mitral Stenosis, Circulation **5**:271, 1952.
12. Ames, W. H., Theilen, E. O., Ehrenhaft, J. L., and Culbertson, J. W.: Study of Left Atrial Pressure Waves in Relation to Pulmonary "Capillary" Pressure Waves in Patients With Mitral Stenosis, J. Clin. Invest. **31**:614, 1952.
13. Connolly, D. C., Tomkins, R. G., Lev, R., Kirklin, J. W., and Woods, E. H.: Pulmonary-Artery Wedge Pressures in Mitral Valve Disease; Relationship to Left Atrial Pressures, Proc. Staff Meet., Mayo Clin. **28**:72, 1953.
14. Werkö, L., Biörck, G., Crafoord, C., Wulff, H., Krook, H., and Eliasch, H.: Pulmonary Circulatory Dynamics in Mitral Stenosis Before and After Commissurotomy, Am. Heart J. **45**:477, 1953.
15. Taquini, A. C., Donaldson, R. J., Ballina, E. S., D'aiutolo, R. E. H., and Lozada, B. B.: Physiologic Studies in Mitral Stenosis, Am. Heart J. **45**:691, 1953.
16. Cosby, R. S., Griffith, G. C., Levinson, D. C., Zinn, W. J., Oblath, R. W., Dimitroff, S. P., and Herman, L. E.: The Physiologic Evaluation of Patients Before and After Mitral Commissurotomy, Dis. Chest. **23**:499, 1953.
17. Yu, P. N. G., Simpson, J. H., Lovejoy, F. W., Jr., Joos, H. A., and Nye, R. E., Jr.: Studies of Pulmonary Hypertension IV. Pulmonary Circulatory Dynamics in Patients With Mitral Stenosis at Rest, Am. Heart J. **47**:330, 1954.

18. Dexter, L., Whittenberger, J. L., Gorlin, R., Lewis, B. M., Haynes, F. W., and Spiegl, R. J.: The Effect of Chronic Pulmonary Disease (Cor Pulmonale and Hypoxia) on the Dynamics of Circulation in Man, Tr. A. Am. Physicians **64**:226, 1951.
19. Fowler, N. O., Jr., Westcott, R. N., and Scott, R. C.: Pulmonary Artery Diastolic Pressure: Its Relationship to Pulmonary Arteriolar Resistance and Pulmonary "Capillary" Pressure, J. Clin. Invest. **31**:72, 1952.
20. Yu, P. N. G., Lovejoy, F. W., Jr., Joos, H. A., Nye, R. E., Jr., and McCann, W. S.: Studies of Pulmonary Hypertension I. Pulmonary Circulatory Dynamics in Patients With Pulmonary Emphysema at Rest, J. Clin. Invest. **32**:130, 1953.
21. McKusick, V. A.: Chronic Constrictive Pericarditis. I. Some Clinical and Laboratory Observations, Bull. Johns Hopkins Hosp. **90**:3, 1952.
22. Scannell, J. G., Myers, G. S., and Friedlich, A. L.: Significance of Pulmonary Hypertension in Constrictive Pericarditis, Surgery **32**:184, 1952.
23. Sawyer, C. G., Burwell, C. S., Dexter, L., Eppinger, E. C., Goodale, W. T., Gorlin, R., Harken, D. E., and Haynes, F. W.: Chronic Constrictive Pericarditis: Further Consideration of the Pathologic Physiology of the Disease, Am. Heart J. **42**:207, 1952.
24. Lewis, B. M., Houssay, H. E. J., Haynes, F. W., and Dexter, L.: The Dynamics of Both Right and Left Ventricles at Rest and During Exercise in Patients With Heart Failure, Circulation Res. **1**:312, 1953.
25. Fowler, N. O.: Cardiac Catheterization in the Diagnosis of Adult Heart Disease, Ann. Int. Med. **38**:478, 1953.
26. Dow, J. W., Levine, H. D., Elkin, M., Haynes, F. W., Hellems, H. K., Whittenberger, J. W., Ferris, B. G., Goodale, W. T., Harvey, W. P., Eppinger, E. C., and Dexter, L.: Studies of Congenital Heart Disease IV. Uncomplicated Pulmonary Stenosis, Circulation **1**:267, 1950.
27. Calazel, P., Gerard, R., Daley, R., Draper, A., Foster, J., and Bing, R. J.: XI. A Comparison of the Right and Left Auricular, Capillary and Pulmonary Artery Pressures in Nine Patients With Auricular Septal Defect, Bull. Johns Hopkins Hosp. **88**:20, 1951.
28. Pederson, A., and Warburg, E.: "Starling's Law of the Heart" Elucidated Through the Filling Pressure of the Right Ventricle in Atrial Septal Defect, Cardiologia **21**:517, 1952.
29. Swan, H. J. C., Zapata-Diaz, J., Burchell, H. B., and Wood, E. H.: Pulmonary Hypertension in Congenital Heart Disease, Am. J. Med. **16**:12, 1954.
30. Joos, H. A., Yu, P. N. G., Lovejoy, F. W., Jr., Nye, R. E., Jr., and Simpson, J.: Clinical and Hemodynamic Studies of Congenital Pulmonic Stenosis With Intact Ventricular Septum, Am. J. Med. **17**:6, 1954.
31. Yu, P. N., Lovejoy, F. W., Jr., Joos, H. A., and Nye, R. E., Jr.: Studies of Pulmonary Hypertension V. Syndrome of Patent Ductus Arteriosus With Marked Pulmonary Hypertension, Am. Heart J. **48**:544, 1954.
32. Dexter, L., Whittenberger, J. L., Haynes, F. W., Goodale, W. T., Gorlin, R., and Sawyer, C. G.: Effect of Exercise on the Circulatory Dynamics of Normal Individuals, J. Appl. Physiol. **3**:439, 1951.
33. Gorlin, R., Sawyer, C. G., Haynes, F. W., Goodale, W. T., and Dexter, L.: III. Effects of Exercise on Circulatory Dynamics in Mitral Stenosis, Am. Heart J. **41**:192, 1951.
34. Witham, A. C., and Fleming, J. W.: The Effect of Epinephrine on the Pulmonary Circulation in Man, J. Clin. Invest. **30**:707, 1951.
35. Fowler, N. O., Westcott, R. N., Scott, R. C., and McGuire, J.: The Effect of Nor-Epnephrine Upon Pulmonary Arteriolar Resistance in Man, J. Clin. Invest. **30**:517, 1951.
36. Doyle, J. T., Wilson, J. S., Estes, E. H., and Warren, J. V.: The Effect of Intravenous Infusion of Physiologic Saline Solution on the Pulmonary Arterial and Pulmonary Capillary Pressure in Man, J. Clin. Invest. **30**:345, 1951.
37. Björk, V. O., Malmstrom, G., and Uggla, L. G.: Left Atrial and Pulmonary "Capillary" Pressure Curves During Valsalva's Experiment, Am. Heart J. **47**:635, 1954.
38. Westcott, R. N., Fowler, N. O., Scott, R. C., Hauerstein, V. D., and McGuire, J.: Anoxia and Human Pulmonary Vascular Resistance, J. Clin. Invest. **30**:957, 1951.
39. Doyle, J. T., Wilson, J. S., and Warren, J. V.: The Pulmonary Vascular Responses to Short-Term Hypoxia in Human Subjects, Circulation **5**:263, 1952.
40. Lenègre, J., Screbat, C., Besson, H., Benchemou, F., and Damien, J.: Pulmonary Capillary Pressure in Various Types of Heart Disease, Arch. mal coeur. **46**:1, 1953 (Abstract in Circulation **8**:941, 1953).
41. Cournand, A., and Ranges, H. A.: Catheterization of the Right Auricle in Man, Proc. Soc. Exper. Biol. & Med. **46**:462, 1941.
42. Dow, J. W., and Gorlin, R.: Pulmonary "Capillary" Pressure as an Index of Left Atrial Mean Pressure in Dogs, Fed. Proc. **9**:33, 1950.
43. Wilson, R. H., McKenna, W. T., Johnson, F. E., Jensen, N. K., Mazzitello, W. F., and Dempsey, M. E.: The Significance of the Pulmonary Artery Wedge Pressure, J. Lab. & Clin. Med. **42**:408, 1953.
44. Wiggers, C. J.: Pulmonary Wedge Catheter Pressures, Editorial, Circulation Res. **1**:371, 1953.

THE THREE MAIN VECTORS OF THE VENTRICULAR ACTIVATION PROCESS IN THE NORMAL HUMAN HEART

I. Its Significance

DANTE PEÑALOZA, M.D.,* AND JOÃO TRANCHESI, M.D.**

MEXICO CITY, D. F.

IN the last four years we have been studying, by means of multiple simultaneous leads, the electrical field created at the body surface by the normal human heart. We observed that in some of the peripheral and thoracic leads, the QRS complex shows very frequently the presence of three main deflections whose peaks correspond to the three main directional changes of the normal spatial vectorcardiogram (VCG). For instance, in the high anterior chest wall, complexes of the rSr′ type can be registered, while on the left basal region of the thorax complexes of the qRs type are frequently recorded. Each deflection of the former is synchronous, respectively, with each one of the latter type of complexes. When only two deflections are inscribed it is possible to disclose, specially in high-speed records, a notch, a slurring, or a change in direction and/or speed in the inscription of the scalar curve. In these cases one of the directional changes of the vectorcardiographic loop is not registered in the electrocardiogram under the form of a distinct deflection due to the fact that the exploring angle is not a favorable one.

These observations lead us to think that in the ventricular activation process (V.A.P.), three main instantaneous vectors can be considered as the fundamental ones for explaining the morphology of the complexes, that is, these three vectors have a definite expression on the electrocardiogram. They, having a common origin, would reach the points corresponding to each one of the three principal directional changes of the vectorcardiographic curve.

Therefore, we thought that through vectorial analysis of the QRS complex it would be possible to demonstrate the existence and spatial direction of these three main vectors. Gardberg and Ashman[1,2] based upon experimental work have considered in the human V.A.P. six spatial instantaneous vectors. Through the knowledge of the sequence of these different vectors they drew sketches which have been used to determine the anatomic position of the heart. However, the study of the electrocardiogram does not permit an easy individualization of these six vectors, and, on the other hand, this was not the purpose of these authors.

From the Department of Electrocardiography of the Instituto Nacional de Cardiología de México, Mexico City, D. F.

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*Research Fellow; Present address: Department of Cardiology, Hospital "Arzobispo Loayza," and Institute of Andean Biology, Faculty of Medicine, Apartado 1116, Lima, Perú.

**Research Fellow; Present address: Hospital das Clinicas, 2a, Clinica Médica, Sao Paulo, Brasil.

Grant[3,4] considers in general terms only the predominance of positivity and negativity of the QRS complex and the spatial direction of the mean vector in the V.A.P. Nevertheless, this author sometimes determines vectors which he names: 0.02, 0.04, and 0.08. These are mean vectors which represent, respectively, the sum of the activation process in the first 0.02 and 0.04 second, and in the last 0.04 second.

The spatial and temporal characteristics of the three vectors proposed, their significance and great help to understand the V.A.P. and, we believe, a fundamental approach to understand the fundamentals of the VCG are the main subjects of the present paper. Successive articles will deal with the relationship between the three vectors and the anatomic position of the heart, on the one hand, and the potential variations at the body surface, on the other. Its modifications under pathologic conditions will be the subject of future publications.

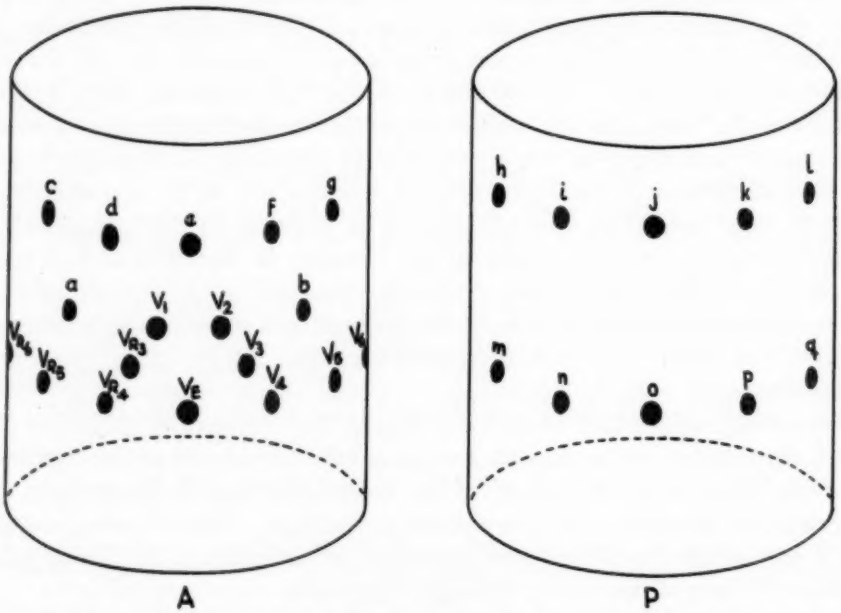

Fig. 1.—Location of the exploring points (most frequently used) and nomenclature of the leads registered at the thoracic surface. *A*, Anterior aspect. *P*, Posterior aspect.

MATERIAL AND METHOD

Twenty-five normal males between 20 and 40 years of age were studied. The electrocardiographic tracings were obtained by means of the direct-writing Sanborn Poly-Viso. Four simultaneous tracings were taken at two different speeds: 25 and 50 mm./sec. The twelve routine leads were recorded. In every patient multiple unipolar thoracic leads were also registered at three horizontal planes, one at the level of the upper limb root, the second one at the level of V_4; the third plane was in an intermedial position passing at the level of V_1 and V_2. The electrodes were placed at the points of intersection of these planes with the midsternal, midclavicular, anterior, middle, and posterior axillary, scapular, and vertebral lines (Fig. 1).

The cube and the equilateral tetrahedron leads[5,6] were frequently used. We modified Grishman's method by placing at the center of the cube, not the anatomic but instead the "electrical center" of the heart. Between these systems and the mapping method quantitative differences do exist, as theoretically expected. We have chosen the multiple-lead recordings since the points of reference are numerous and because the low voltage of the complexes obtained by the other methods makes difficult the correct analysis.

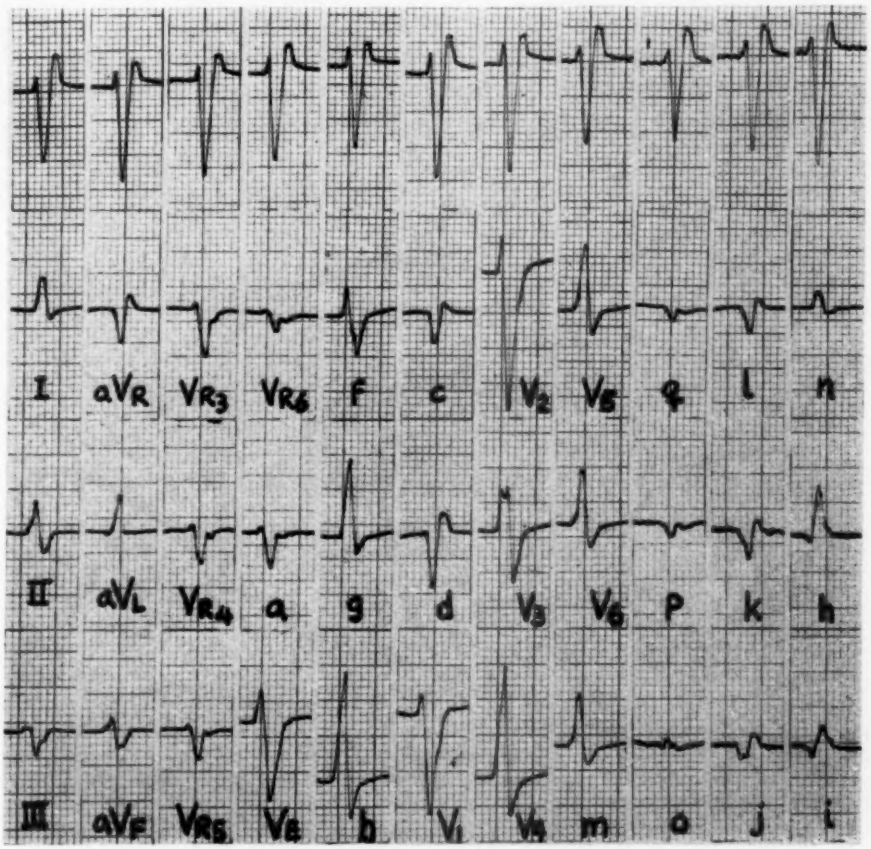

Fig. 2.—Multiple simultaneous leads registered at 50 mm./sec. (Case 3). In the upper row is shown the control lead recorded at point *e*. The three deflections of the ventricular complex appear distinct in this lead. The spatial orientation of each instantaneous vector has been obtained by determining the frontal plane projection of the moment considered, and localizing the zero potential plane.

Example: **To determine the direction of the third vector, we look for its projection on the frontal plane. It is found at −120°, isoelectric in aV_L and negative in standard leads. The null potential plane passes between *e* and *f*, and slightly above *a*, over the anterior aspect. Over the back the transitional plane lies under *h*, and crosses *g*. Thus the direction of this vector is to the right, upward, and backward (see also Fig. 3).**

The spatial direction of the instantaneous vectors was determined by registering at 50 mm./sec. speed. The control lead was any peripheral or thoracic lead in which the three deflections of the QRS complex were clearly distinct. However, we prefer, for technical purposes and precision, to use one of the peripheral leads.

Considering the magnitude and sense of the synchronous deflections (notch, slurring, etc.) in all the points explored, we locate the zone of zero potential for each vector, taking into account the eccentricity of the null potential point. In this manner we determine the spatial direction of the vectors using a model which will be described. An example for determining the spatial orientation of the vectorial forces (Case 3) is shown in Figs. 2 and 3. The leads obtained from the same case are seen in Fig. 4. The arrangement of the leads is in accordance with the location of the corresponding exploring points on the thoracic anterior and posterior surfaces. To control the spatial direction of the vectors thus found, the morphology of the QRS complex for various points explored was inferred and compared with the actual curves. To presume the morphology of the curves a modification of the same model was utilized.

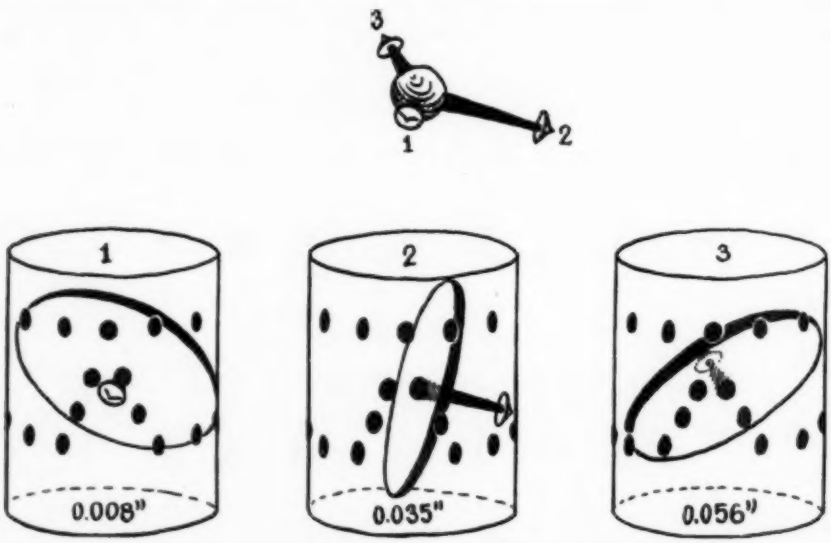

Fig. 3.—The spatial orientation of the three main vectors (Case 3) is shown at the top of the figure. These vectors permit the spatial representation of the V.A.P. in a single plane. The cylinders enclose the null potential plane, the spatial direction of the instantaneous vectors, and consequently the electrical field distribution for each moment.

The relative magnitude of the vectors was calculated in an approximate form based upon the voltage of the three main deflections of the ventricular complex. The inscription moment of the vectors was determined by amplifying the projection on a screen 10 times (1 mm. = 0.002 sec.) the QRS complex in those leads in which the three vectors were distinct.

The model we have devised is a modification of several others.[7-11] The innovations concern the scales, the cylinder representing the thorax, and the electrical center or apparent point of origin of the vectors.

Circumferences graduated in positive values from +1° to +179° and in negative figures from −1° to −179° are used as scales. The frontal plane is seen facing the model; the sagittal plane is seen from the left; and the horizontal plane is seen from above. In the first two planes the axis 0° to ±180° has been drawn horizontally and consequently divides the circle into a superior negative and an

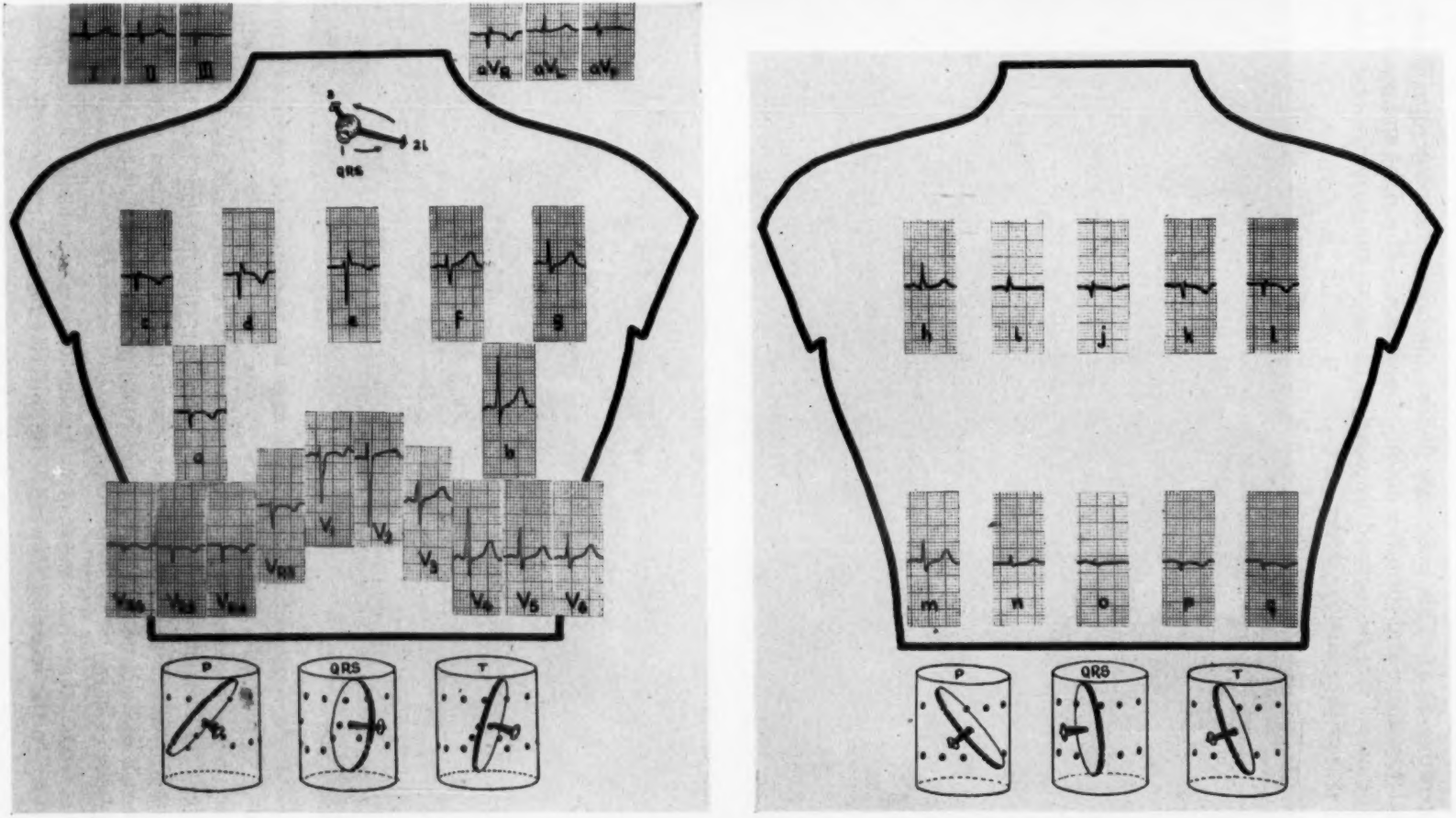

Fig. 4.—Multiple thoracic leads registered at 25 mm./sec. (Case 3). The leads have been so located as to make them coincide with the corresponding exploring points (anteriorly and posteriorly). The spatial orientation for the three main instantaneous vectors of the V.A.P. is shown in the top of the silhouette. Notice the "electrical center" has been arbitrarily displaced for practical purposes. The spatial orientation of P, QRS, and T mean vectors, and the corresponding distribution of the electrical field are seen at the bottom.

inferior positive area. This same axis divides the horizontal plane into halves one anterior, positive and the other posterior, negative. The right and posterior wall of the model can be reclined to expedite access to the posterior and right lateral points of the plastic cylinder.

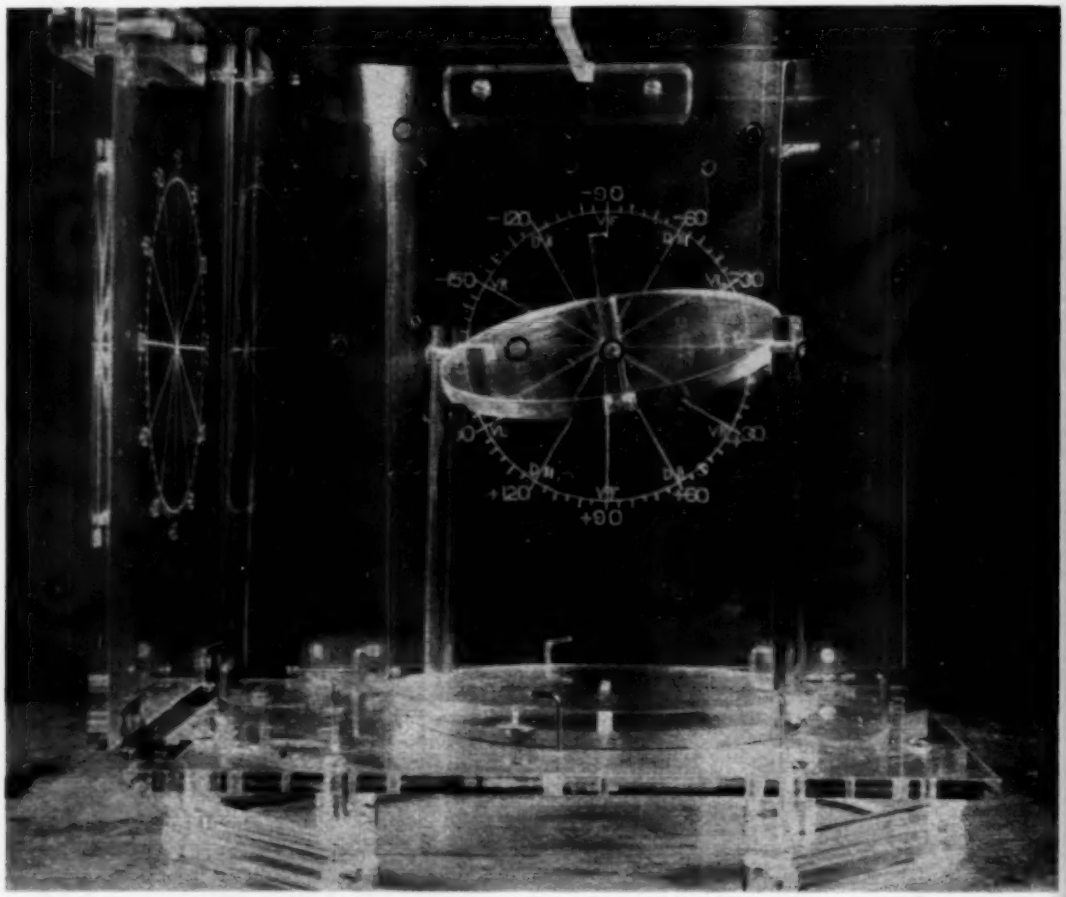

Fig. 5A.—Model used to determine the spatial orientation of a given vector (mean or instantaneous). The elliptical form of the plastic cylinder, representing the thoracic cage, and the eccentricity of the apparent point of origin of the vectors (the projection of the electrical center coincides with V_2), reduce the discrepancies between real and calculated vectors. In this figure is shown a vector projecting at +80° on the frontal plane, with a backward direction. The zero potential plane passes slightly above VR_4, and between V_2 and V_3.

The cylinder representing the thoracic cage has an elliptical form (not circular as usual). It resembles a normosthenic thorax. At the exploring points small holes were made in order to pass sticks connecting the surface of the cylinder to the theoretical electrical center and so represent the different lead lines. In this manner it is rather simple to observe the orthogonal projection of the vectors on a given lead line and infer the approximate morphology of the scalar tracing at the points explored.

The "electrical center" or site of null potential is eccentrically located within the cylinder to the left and forward. Its anterior parietal projection coincides

with V_2 and its left lateral projection is found 15 mm. ahead of V_6, different from* what has been done by Grant and other workers.[7-9] It is interesting to point out that ventricular and auricular activation have their own independent "electrical center", i.e., for the P wave the anterior parietal projection is about 2 cm. above V_1. In order to obtain the different anterior parietal projection of the apparent point of origin of the auricular (V_1) or ventricular (V_2) electrical activity, it is only necessary to give a lateral movement to the whole cylinder. In this form the relative zero potential point remains fixed keeping the same relationship with the center of the three scales.

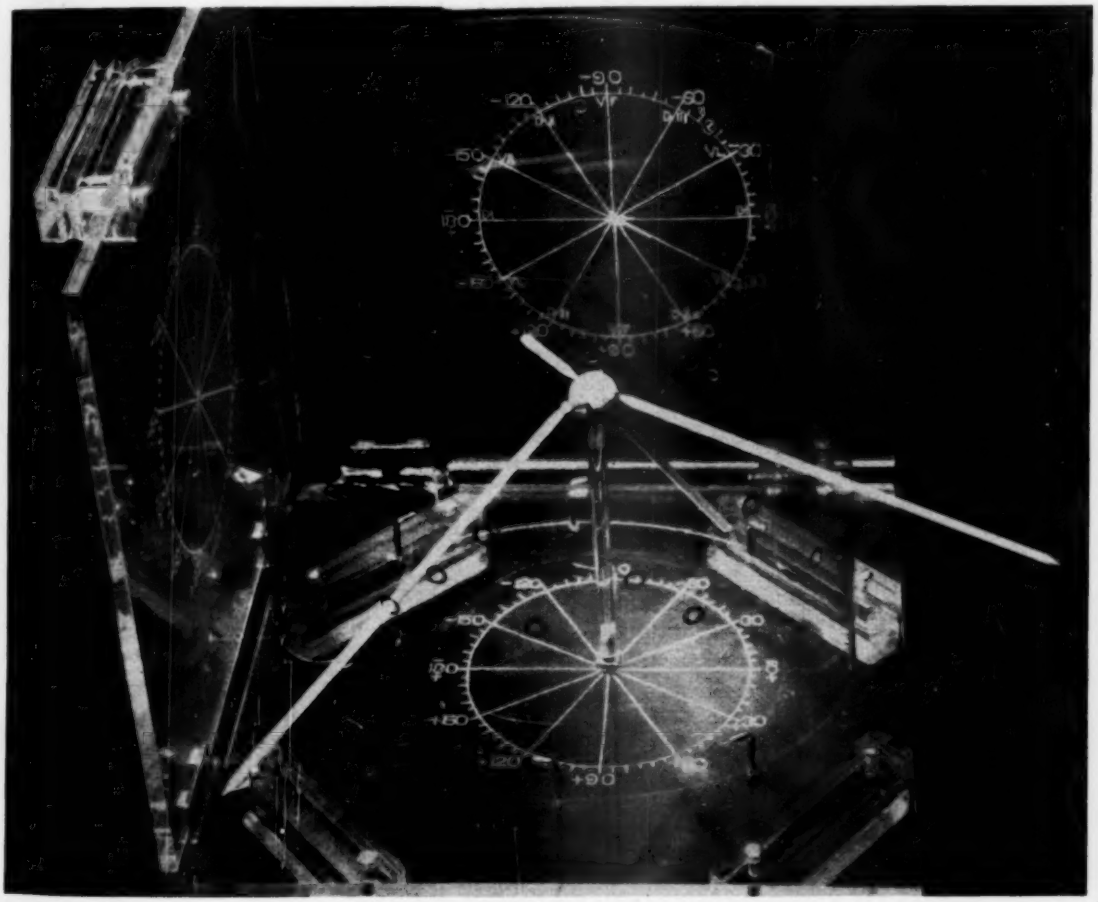

Fig. 5B.—The same model is now shown with the second device. The plastic stem has been screwed in the center of the horizontal scale. It supports a small rubber ball which represents the apparent point of origin of the vectors. Its projection coincides with the center of the three scales. This ball permits the insertion of pin-pointed sticks to represent vectorial forces as well as lead lines. Notice that the former have the usual orientation of the three main vectors of the V.A.P.; the latter go through the holes, made on the plastic cylinder, corresponding to VR_4 and V_6.

*These variations were based upon a series of experiments with the purpose of studying the electrical field of the heart. We have found that for man and for dog the "electrical center" is located above the anatomic center.[12] Jouve and associates[13] and more recently Milnor and associates[14] and Garello[15] obtained similar results using different procedures. The heterogeneity of the conducting medium represents, probably, one of the determining factors, for such position.[16]

TABLE I

NO.	LONGITUDINAL HEART AXIS*	$\hat{A}_{QRS}$	$\hat{A}_T$	$\hat{A}_P$	VECTOR 1			VECTOR 2			VECTOR 3			TIME OF INSCRIPTION (SEC.)			QRS DURATION SEC.
					F	S	H	F	S	H	F	S	H	VECTOR 1	VECTOR 2	VECTOR 3	
1	26.5	+ 95	+55	0	− 70	−135	+ 70	+60	+ 50	−55	+150	+15	−115	0.011	0.037	0.062	0.088
2	29	+ 30	+30	+40	+150	+160	+125	+20	+ 50	−15	−115	−60	−130	0.012	0.044	0.072	0.084
3	30	+ 5	+15	+40	+115	+140	+105	+15	+ 40	−20	−120	−45	−120	0.008	0.035	0.056	0.080
4	31	+ 60	+35	+50	+110	+110	+135	+50	+ 60	−30	−165	−50	−165	0.010	0.040	0.064	0.094
5	32	+ 35	+30	+50	−120	−105	+150	+40	+ 60	−25	−160	−20	−125	0.010	0.044	0.066	0.088
6	33.5	+ 40	+20	+60	+150	+175	+ 95	+40	+ 60	−25	−145	−65	−160	0.011	0.039	0.064	0.078
7	35	+ 60	+40	+55	+150	+150	+140	+60	+ 70	−30	−125	−80	−170	0.011	0.044	0.067	0.084
8	37	+ 30	+30	+60	+165	+150	+155	+50	+ 50	−45	− 95	−65	−100	0.008	0.039	0.060	0.084
9	37	+ 65	+35	+30	−105	−140	+100	+50	+ 65	−30	−170	−45	−170	0.008	0.034	0.060	0.082
10	37	+ 85	+50	+30	− 85	−135	+ 85	+85	+ 65	−80	+130	+65	−155	0.010	0.037	0.056	0.072
11	37.5	+100	+55	+65	− 30	−170	+ 75	+70	+ 60	−60	−135	−70	−160	0.012	0.036	0.056	0.080
12	38	+ 40	+40	+60	−120	−165	+100	+50	+ 60	−35	+130	+35	−120	0.008	0.034	0.054	0.068
13	40	+ 60	+40	+60	− 95	−175	+ 95	+60	+ 55	−45	−120	−70	−150	0.013	0.044	0.066	0.080
14	40	+ 65	+45	+60	− 95	−175	+ 95	+65	+ 60	−50	−120	−45	−120	0.008	0.037	0.063	0.078
15	45	+ 50	+45	+60	−120	−120	+130	+60	+ 50	−70	−100	−90	±180	0.010	0.043	0.062	0.096
16	45	+ 70	+60	+60	− 85	−120	+ 80	+75	+ 60	−70	+120	+30	−110	0.011	0.050	0.082	0.100
17	45	+ 90	+45	+70	− 60	−120	+ 45	+80	+ 65	−70	−145	−30	−130	0.012	0.038	0.072	0.088
18	46	+ 75	+50	+75	− 80	−120	+ 75	+75	+ 75	−60	+120	+45	−120	0.012	0.043	0.064	0.078
19	46	+ 80	+35	+60	− 70	−110	+ 50	+85	+ 75	−80	+135	+45	−155	0.012	0.044	0.062	0.088
20	48	+100	+55	+65	− 40	−125	+ 40	+85	+ 65	−80	−130	−80	−170	0.008	0.044	0.066	0.084
21	49	+ 25	+60	+70	+165	+150	+155	+40	+ 40	−35	−100	−85	−160	0.010	0.042	0.070	0.092
22	49	+ 30	+50	+80	+120	+130	+125	+35	+ 65	−20	−100	−80	−140	0.012	0.036	0.064	0.096
23	49	+ 95	+40	+65	− 90	−150	+ 90	+80	+ 60	−75	+165	+25	−150	0.012	0.045	0.072	0.090
24	36	−100	+50	+50	+105	+105	+145	+30	+130	+35	−110	−65	−130	0.012	0.023	0.045	0.090
25	44	− 95	+40	+60	+ 75	+120	+ 65	+30	+150	+45	−110	−75	−145	0.012	0.022	0.067 0.042 0.070	0.090

*Obtained by x-ray

F= Frontal plane; S = Sagittal plane; H = Horizontal plane.

The form of the cylinder and the eccentric position of the "electrical centers" for P, QRS and T have made it possible to obtain a better orientation for the lead line between the exploring points and the null potential center for each phase of the electrical activity of the heart, i.e., a smaller discrepancy between calculated and real vectors is achieved.

The model is equipped with two different devices. The first one is shown within the cylinder in Fig. 5A. It consists of a plastic circulater plate (null potential plane), 11 cm. in diameter, through the center of which ("electrical center") a pencil-shaped plastic stick 9 cm. in length passes (vectorial force). The plate is in turn mounted on a gyratory base allowing movements in any direction. This part is used for determination of the spatial direction of a single vector (mean or instantaneous).

The second device is seen in Fig. 5B. It consists of a small rubber ball, 1.5 cm. in diameter, mounted on a plastic stem, 11 cm. long. This bar is screwed to the center of the horizontal scale. In this way the rubber ball, representing the apparent origin of the vectors, eccentrically placed, is projected perpendicularly to the center of each one of the three scales. The rubber sphere permits the sticking of thin plastic bars, some of them representing mean or instantaneous vectors and some others the lead lines for the different exploring points.

The morphology of the QRS complex, at any point of the body surface, the SĜ, the SÂQRS-SÂT angle or any other determination using two or more vectors can be obtained with the second set.

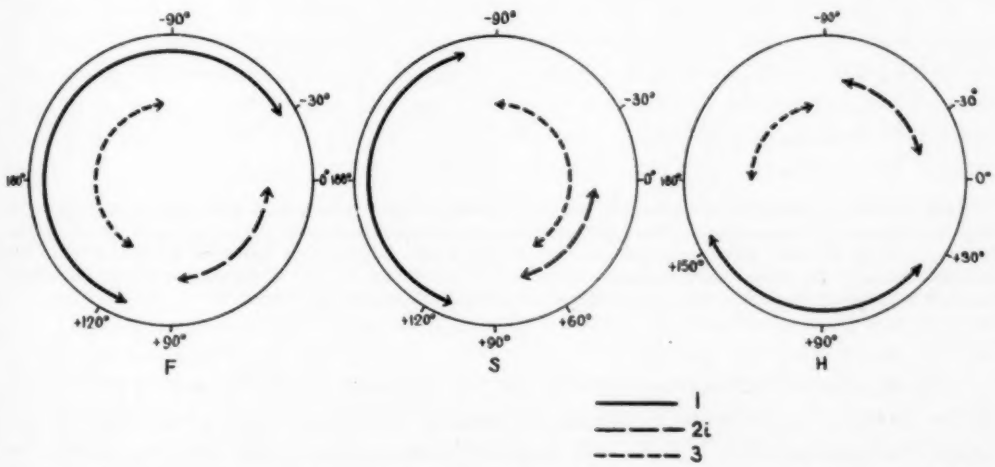

Fig. 6.—The distribution of the vectors *1*, *2i*, and *3* on the frontal (*F*), sagittal (*S*), and horizontal (*H*) planes is represented. Observe, that the first vector orients forwardly to the right, and sometimes to the left and upward. Vectors *2i* and *3* point to the back, the *2i* vector to the left and downward, and the third vector to the right.

RESULTS

Table I and Fig. 6 summarize our results. The number of cases studied in our series permits one to know the sequence of the normal V.A.P., but not to establish normal limits for the orientation of the three main vectors. On the other hand, two of the cases were chosen because their ÂQRS values were unusual. Therefore, no attempt to draw statistical conclusions has been made.

Vector 1.—

(*a*) *Occurrence and module*: The first vector has an average time of inscription of 0.010 second after the onset of the ventricular depolarization. The limit values found are: 0.008 second and 0.013 second. Of the three vectors this one has the smallest magnitude.

(*b*) *Orientation on the frontal plane*: It is frequently located in Bayley's 2, 3, and 4 sextants. In a heart with an intermediate position and without rotation, the direction of the first vector is to the right and upward, with a frontal projection around −130°. In a very few instances it can be located in sextants 1 and 5, in zones proximal to sextants 2 and 4, respectively. The extreme values found in our series are −30° and +110°. However, in cases with atypical activation (Cases 24 and 25, Table I) the values can be far beyond this.[17]

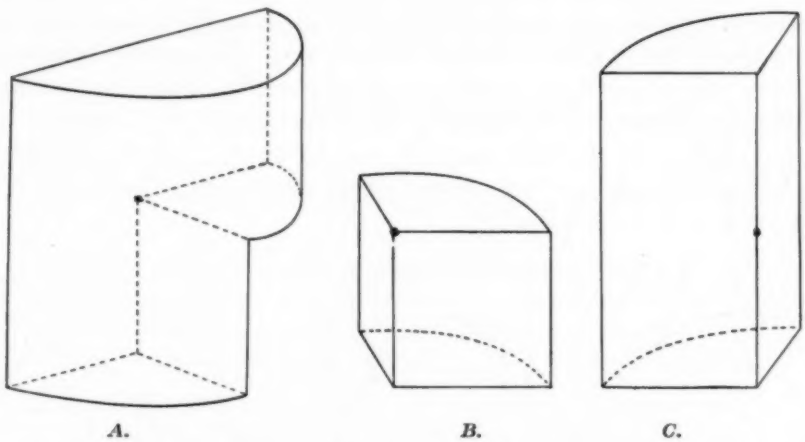

Fig. 7.—*A*, A hemicylinder excluding the left inferior octant represents all the possible orientations that the first vector may assume. The point of origin of the vector is located at the center of the cylinder, from which the sketches have been derived. *B*, Shows a left, inferior and posterior octant of cylinder corresponding to the most frequent spatial distribution for vector *2i*. *C*, Represents a right, posterior quarter of cylinder, in which can be considered all possible situations for vector *3*.

(*c*) *Spatial orientation*: The first vector has systematically a forward sense. If the center of a cylinder is considered as the "electrical center" of the vectors originated during the V.A.P., all possible directions of this vector would be encountered in the anterior hemicylinder, excluding the left inferior octant (Fig. 7,A). Nevertheless, it can also be found in this region in cases with atypical activation.

In a subsequent paper, relations between the spatial position of the heart and the first vector will be discussed.[17] For the moment it is important to know that this vector points forward, upward, and to the right in a heart in the intermediate position without rotation. In a horizontal heart with counterclockwise rotation, the first vector goes forward, downward, and to the right. In a vertical clockwise rotated heart this vector points forward, upward, and to the left.

Vector 2.—

(*a*) *Occurrence and module*: The second vector is inscribed, on an average, at 0.040 second after the onset of the ventricular complex. The limit values for the inscription of this vector are: 0.034 and 0.050 second. In general terms it occurs early when the QRS duration is short, and a late inscription is seen when the QRS duration is long. This same is valid for vectors 1 and 3, with the exception of those cases with atypical activation. For instance, in cases 24 and 25 with ÂQRS at −100° and −95°, respectively, the QRS duration is 0.090 second and the inscription time for the second vector is rather early: 0.023 and 0.022 second, respectively. In these cases the second vector has some other singular characteristic, i.e., it is of a small magnitude and points forward. The atypical V.A.P. observed in cases with a normal heart will be the subject of a next paper.[17] As a rule, the magnitude of the second vector is greater than that of the other two vectors.

(*b*) *Direction on the frontal plane*: This vector is frequently found in the last sextant and in the adjacent half of the fifth sextant. The limits for our series are: +15° and +85°, although ÂQRS may go beyond these figures in several instances. Theoretically speaking, these limits could be considered as −30° and +105°, respectively.[17]

(*c*) *Spatial sense*: In normal cases the second vector goes backward. This vector is spatially oriented to the left, downward, and backward. All possible spatial directions of this vector can be enclosed in the octant of a cylinder as shown in 7, *B*. In general terms, vectors which are more vertical belong to vertical hearts but may also be seen in intermediate and horizontal hearts with clockwise rotation (Case 1). Similarly, vectors which are more horizontal are found in horizontal hearts but may also be seen in intermediate and even in vertical hearts with counterclockwise rotation (Cases 21 and 22).[17] In cases with atypical activation, the early predominance of the basal or terminal vectors counterbalance the second vector electrical effects, and this makes the second directional change occur sooner and point forward.

Vector 3.—

(*a*) *Occurrence and module*: The third vector is inscribed, at 0.064 second after the beginning of the V.A.P. The limit values for the inscription of this vector are: 0.054 and 0.082 second. As a rule, the magnitude of vector 3 is small, but rather frequently it is greater than that of vector 1. The earlier the basal vector is inscribed the greater its magnitude and the probabilities for ÂQRS to deviate to unusual positions. In these atypical cases, the magnitude of the basal vectors is definitely superior to that of the other two vectors, although the sense remains unchanged.

(*b*) *Direction on the frontal plane*: This is very frequently observed lying on sextant 3 and in the half adjacent to sextant 2, i.e., it goes upward and to the right. Sometimes there is a forward shift of the vectorcardiographic loop and vector 3 lies on sextant 4 (downward and to the right). This is particularly seen in some horizontal hearts with clockwise rotation. The limit values found for the direction of the third vector on the frontal plane are: −95° and +120°.

(*c*) *Spatial orientation*: The third vector goes always backward. The possible spatial orientation of the third vector would be encountered in the right and posterior quadrant of a cylinder as represented in Fig. 7, *C*.

DISCUSSION

Factors such as the heterogeneity of the media surrounding the heart,[18-20] the eccentricity of the viscus,[21-24] and the different systems of leads[25-28] may determine discrepancies between calculated and real vectors. However, generally speaking, two are the main responsible factors for the characteristics of the three vectors described, or of any cardiac vector, namely, the way the heart is activated and the cardiac position within the thoracic cage.

The V.A.P. creates at the epicardial surface of the heart an electrical field which corresponds to a complex system of dipoles.[32-34] On the contrary, this electrical field at the body surface is similar to that produced by a single dipole.[12,35-39]* Hence, it is possible to consider a positive and negative region separated by a narrow zone of null potential. This is valid for the whole process as well as for any moment of the ventricular activation. The three vectors described or any other instantaneous vector can be considered as the sum of multiple electrical forces occurring at that particular moment.

If the sequence of the V.A.P. remains unchanged the spatial orientation of the vectors varies mainly in accordance with the cardiac position. The differences in the vectorial orientation observed from one person to another,[17] as well as those seen between man and dog, are mainly explained through the variations† on the cardiac position,[12] since the sequence of the ventricular depolarization can be considered similar. This concept must be kept in mind when studying the significance of the three main vectors.

The First Vector.—The experimental work on dogs has shown that at 0.010 second after the onset of the V.A.P., all the left surface of the intraventricular septum and most of the septal mass activated by the left bundle branch (including some areas of the right septal surface) are depolarized.[40] Something similar is to be expected when we consider the process of activation in the human being. Even though the V.A.P. is rather complex during the first hundredth of a second, it may be represented by a single vector, when dealing with the peripheral electrical field of the heart. To reinforce the statement that the first vector represents essentially the early activation process of the septal mass, it must be remembered that in the man it points always forward (the left septal surface is posterior and the right is anterior). We designate this electrical force as "vector 1" or "septal vector".

In some normal cases, Grant related the orientation of the "0.02" second mean vector to the spatial position of the interventricular septum as it is found at the autopsy table.[4] This vector was seen oriented tangentially and not perpen-

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*Occasionally, when exploring precordial points proximal to the ventricular mass (V_2, V_3, and V_4) the curves so obtained cannot be satisfactorily explained through a single dipole. This suggests that the electrical field can sometimes be distorted in the precordial region, probably due to the presence of local forces; however, this effect is, in general terms, of minor importance as it has been pointed out.[29-31]

†The dog has a vertical heart with counterclockwise rotation. The human heart is less vertical than that of the dog. The right ventricle is essentially anterior, and the left ventricle is posterior. The interventricular septum is oriented almost parallel to the frontal plane and not perpendicular as it is in the dog.[12]

dicularly to the septal mass. Grant concluded that pure septal vectorial forces are manifested before 0.02 second. These findings agree with our results.

Fowler and Helm,[41] more recently, have studied the spatial direction of the initial component of the VCG loop in eighteen normal subjects. These investigators found that for most of the cases, the vectorcardiographic loop is oriented forward and to the right during the first 0.008 second. It continues, usually, to the left, downward, and forward, at 0.012 second. This means that the vector inscribed at this time represents the summation of septal and left free ventricular wall forces.

The Second Vector.—Of the three vectors, the second has the greatest magnitude. It is inscribed at 0.040 second, as an average. At this moment multiple regions of the ventricular mass (including the interventricular septum) are being activated.[42] The nearly constant direction of this vector, backward, to the left and downward, indicates that the global electrical effect is similar to that of a dipole with its positivity oriented toward the left ventricle, in which the electrical forces predominate at that moment. This is the reason we designate this vector as "vector 2i"* or "left ventricular vector". We may assume that at this time there is another vector present: "vector 2d"† or "right ventricular vector" whose electrical effect is masked for the stronger activation forces of the left ventricular mass and only in cases of accentuated right ventricular hypertrophy could it be manifested.

Grant considers a "0.04" vector, oriented to the left and forward,[3] which does not coincide with the direction of our "vector 2i". This can be easily understood since Grant's vector 0.04 is not an instantaneous one, but a mean vector instead, enclosing the whole activation process up to 0.04 second. This lapse is rather prolonged and, therefore, the vector corresponds only in a very broad sense, as admitted by this author, to the activation of a certain anatomic region.

The Third Vector.—This vector is inscribed, on an average, 0.064 second after the onset of the ventricular electrical systole. We must keep in mind that the whole V.A.P. in the dog's heart requires about 0.060 second, while in the man's heart the duration is around 0.085 second. Therefore, we have to admit that at 0.064 second the depolarized regions in the man's heart are those which in the dog's heart become activated at 0.045 to 0.050 second, i.e., the basal portions of both ventricle and of the interventricular septum. For the above reason we have named this vector as "basal vector" or "vector 3". The basal portions of the human heart are placed to the right, upward and backward, and this is just the spatial direction followed by "vector 3", in an intermediate position of the heart. In the canine heart, in view of the counterclockwise rotation and the upward position of the basal pole, the "basal vector" points to the left and upward.[12]

The "0.08" Grant's vector,[3] which actually is a mean vector enclosing the second half of the V.A.P., is oriented to the left and backward and not with the usual direction of our "vector 3".

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*i stands for "izquierdo" (Spanish word meaning left).
†d stands for "derecho" (Spanish word meaning right).

The terminal part of the V.A.P. has been referred to several ventricular regions. Gardberg and Ashman[1] believe that the late activation of the pulmonary conus, together with that of the basal and posterolateral portions of the left ventricle, are responsible for the terminal part of the QRS complex. They interpreted the late positivity in the high precordial leads as a result of the activation of the underlying pulmonary conus. However, it seems that the depolarization of this region is relatively early, in man.[43] On the other hand, it is unnecessary to try to explain that late positivity through the activity of the free wall of the pulmonary conus or by the forward sense of terminal vectors.[44]

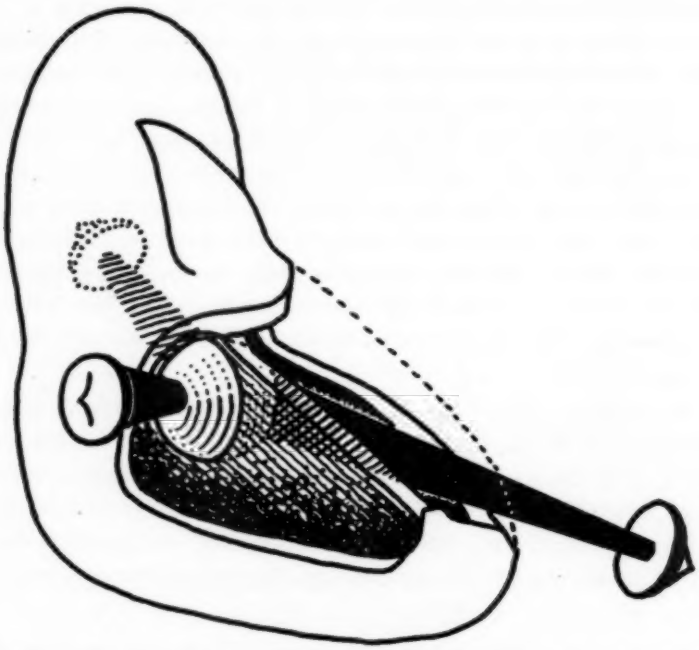

Fig. 8.—This shows the spatial relationship among different regions of the normal human heart (interventricular septum, free left ventricular wall, and basal areas) and each one of the three main vectors of the V.A.P.

Kossmann and associates[45] relate the late positivity in supraventricular intracavity leads (superior vena cava, right atrium, pulmonary artery) to the depolarization of the crista supraventricularis. Sodi-Pallares and associates[40] believe that this deflection in tracings taken in the right atrial cavity is due to the activity of some basal regions of the interventricular septum, i.e., "those proximal to the insertion of the tricuspid and pulmonary valves."

Considering the direction of the human third vector, we believe that the main contribution to its formation belongs to the inner part of the left ventricular basal region, to the crista supraventricularis and to those septal regions pointed out by Sodi-Pallares and associates.[40]

Fig. 8 shows the spatial relationship between different regions of the heart (interventricular septum, free left ventricular wall, and basal areas) and each one of our three vectors. This is only a schematic representation since the vectors

and their point of origin are inferred from the study of the electrical field created at the body surface by the heart. Within the ventricular mass the electrical phenomena are rather complex as has already been pointed out.

ADVANTAGES OF METHOD DESCRIBED

The utilization of vectorial analysis in the study of the V.A.P. increases the value of this method. The spatial orientation of the three vectors drawn in a single plane facilitates the representation of the spatial sequence of the V.A.P.

If we know the spatial characteristics of these vectors in a given subject, we can infer the potential variations occurring at any point of the body surface (or at deeper regions inside the body), if the spatial direction of the lead line is taken into account. On the other hand, this has an obvious advantage over any planar projection of the VCG which permits deduction of the morphologic variations only at points located on the projection plane.

The underestimation of this important point of view has led to fallacious conclusions, for instance, to the statement that there are discrepancies between precordial leads and horizontal VCG, forgetting that the precordial registration points are placed at three different planes.[44]

The knowledge of the spatial and temporal characteristics of the three main vectors representing the ventricular electrical systole, together with the studies upon spatial location of the human heart, may furnish the necessary data to follow the spatial invasion of the ventricular myocardium by the activation crest. To explain the origin of each one of the three vectors there has been considered the instantaneous predominance of electrical forces created in a given cardiac region during the V.A.P.

SUMMARY

A study of the ventricular activation process (V.A.P.) at the body surface of normal subjects has been carried out by means of multiple simultaneous electrocardiographic leads. In order to reduce the discrepancies between real and calculated vectors, the vectorial analysis was facilitated by means of a plastic model in which the form of the thoracic cage as well as the location of the apparent "electrical center" was particularly considered.

Three main instantaneous vectors corresponding to the V.A.P. are described. The first vector ("vector 1" or "septal vector") orients always forward and, as a rule, to the right; it represents early septal electrical forces. The second vector ("vector 2i" or "left ventricular vector") points to the left, downward, and backward, toward the free left ventricular wall. It corresponds to the predominant electrical activity originated in this ventricle. The third vector ("vector 3" or "basal vector") goes, usually, backward, to the right, and upward. It represents the deplorization of basal regions of the ventricular mass, including the septum.

These three vectors are inscribed, on an average, at 0.010, 0.040, and 0.064 second, respectively, after the onset of the QRS complex. The determination of the three vectors from the scalar curve permits one to follow the spatial se-

quence of the ventricular activation process and to infer the potential variations at different points of the body surface.

We are indebted to Prof. Demetrio Sodi-Pallares and Dr. Fernando Cisneros for the facilities and valuable criticism which made possible the preparation of this article.

REFERENCES

1. Gardberg, M., and Ashman, R.: The QRS Complex of the Electrocardiogram, Arch. Int. Med. **72**:210, 1943.
2. Ashman, R.: Estimation of Heart Position From the QRS Complex of the Electrocardiogram, Arch. Inst. cardiol. México **16**:139, 1946.
3. Grant, R. P.: Spatial Vector Electrocardiography. A Method for Calculating the Spatial Electrical Vectors of the Heart From Conventional Leads, Circulation **2**:676, 1950.
4. Grant, R. P.: The Relationship Between the Anatomic Position of the Heart and the Electrocardiogram. A Criticism of "Unipolar" Electrocardiography, Circulation **7**:890, 1953.
5. Grishman, A., Borun, E. R., and Jaffe, H. L.: Spatial Vectorcardiography: Technique for the Simultaneous Recording of the Frontal, Sagittal and Horizontal Projections, Am. Heart J. **41**:483, 1951.
6. Wilson, F. N., Johnston, F. D., and Kossman, C. E.: The Substitution of a Tetrahedron for the Einthoven Triangle, Am. Heart J. **33**:594, 1947.
7. Grant, R. P., and Estes, E. H., Jr.: Spatial Vector Electrocardiography, Philadelphia, 1952, The Blackiston Company.
8. Urschel, D. L., and Abbey, D. C.: Modification of a Vector Model to Provide Accurate Recording of Mean Vector Positions in Three Planes of Space, Am. Heart J. **44**:372, 1952.
9. Woodson, G. C., Jr., and Hurst, J. W.: A Teaching Aid for Visualizing the Direction of Electrical Forces of the Heart in Space, Am. Heart J. **44**:879, 1952.
10. Langner, P. H., Jr.: A Geometric Model for Determining the Direction of Mean Spatial Vector, Am. Heart J. **44**:378, 1952.
11. Simonson, E.: A Spatial Vector Analyser for the Conventional Electrocardiogram, Circulation **7**:404, 1953.
12. Peñaloza, D., and Tranchesi, J.: Unpublished observations.
13. Jouve, A., Buisson, P., Albouy, M., Velasque, P., and Bergier, G.: Le Pointe Origine de la boucle vectocardiographique. Sa détermination. Son importance pratique, Arch. mal. coeur **43**:215, 1950.
14. Milnor, W. R., Talbot, S. A., and Newman, E. V.: A Study of the Relationship Between Unipolar Leads and Spatial Vectorcardiograms, Using the Panoramic Vectorcardiograph, Circulation **7**:545, 1953.
15. Garello, L.: Homogeneité du champ electrique thoracique et origine du vectorcardiogramme spatial, Acta cardiol. **8**:118, 1952.
16. Cabrera, E.: Personal communication.
17. Peñaloza, D., Tranchesi, J., and Cisneros, F.: The Three Main Vectors of the Ventricular Activation Process in the Normal Human Heart. II. Its Variation With the Cardiac Position, (To be published).
18. (a) Burger, H. C., and van Milaan, J. B.: Heart-Vector and Leads, Part II, Brit. Heart J. **9**:154, 1947.
    (b) Burger, H. C., van Milaan, J. B., and Den Boer, W.: Comparisons of Different Systems of Vectorcardiography, Brit. Heart J. **14**:401, 1952.
19. Benjamin, J. M., Jr., Schwan, H., Kay, C. F., and Hafkenschiel, J. H.: The Electrical Conductivity of Living Tissues as It Pertains to Electrocardiography, Circulation **2**:321, 1950.
20. Cabrera, E., and Hernández Aguilar, E.: Estudio del campo eléctrico del corazón por derivaciones ortogonales, Arch. Inst. cardiol. México **22**:121, 1952.
21. Wilson, F. N., and Bayley, R. H.: The Electrical Field of an Eccentric Dipole in a Homogeneous Spherical Medium, Circulation **1**:84, 1950.
22. Selvini, A., Pilotti, A., and Lanza, F.: Etude vectorielle des derivations electrocardiographiques, Cardiologia **16**:92, 1950.
23. Schaffer, A. I., Dix, J. H., and Bergmann, P. G.: The Effect of Eccentricity on Spatial Vector Analysis of the Electrocardiogram of the Newborn Infant and on the Correlation Between the Electrocardiogram and the Vectorcardiogram, Am. Heart J. **43**:735, 1952.
24. Frank, E.: A Comparative Analysis of the Eccentric Double-Layer Representation of the Human Heart, Am. Heart J. **46**:364, 1953.

25. Cabrera, E., and Sodi-Pallares, D.: Factores que intervienen en la amplificación de las derivaciones bipolares y su aplicación a la vectocardiografía, Arch. Inst. cardiol. México **19**:91, 1949.
26. Cronvich, J. A., Conway, P., and Burch, G. E.: Standardizing Factors in Electrocardiography, Circulation **2**:111, 1950.
27. McFee, R., and Johnston, F. D.: Electrocardiographic Leads. I. Introduction, Circulation **8**:554, 1953. II. Analysis, **9**:255, 1954. III. Synthesis, **9**:868, 1954.
28. Brody, D. A., and Romans, W. E.: A Model Which Demonstrates the Quantitative Relationship Between the Electromotive Forces of the Heart and the Extremity Leads, Am. Heart J. **45**:263, 1953.
29. Fattorusso, V., Thaon, M., and Tiltmant, J.: Contribution a l'Etude de l'electrocardiogramme precordial, Acta cardiol. **4**:464, 1949.
30. Holzmann, M.: Der neuste Stand der Brustwandelektrokardiographie, Ztschr. Kreislaufforschg. **40**:577 (I), 660 (II) and 732 (III), 1951.
31. Böckh, E. M., and Schaefer, H.: Weitere Untersuchungen über die Konstruierbarkeit von Ekg.-Vektoren aus Brustwandableitungen, Cardiologia **23**:191, 1953.
32. Goldberg, H., and Eyster, J.: The Relation of Electrical and Mechanical Events in the Ventricle of the Turtle, Am. J. Physiol. **128**:390, 1939.
33. Selvini, A.: Sull'interpretazione dell'elettrocardiogramma ottenuto in derivazione unipolare diretta con particolare riguardo al significato della cosidetta oscillazione intrinseca, Fol. Cardiol. **4**:1, 1944.
34. Levine, H.: Personal communication.
35. Waller, A. D.: On the Electromotive Changes Connected With the Beat of the Mammalian Heart and of the Human Heart in Particular, Philosoph. Trans. Roy. Soc. S. A. **180**:169, 1889.
36. Ashman, R., Ferguson, F. P., Gremillion, A. I., and Byer, E.: The Normal Human Ventricular Gradient. V. The Relationship Between AQRS and G, and the Potential Variations of the Body Surface, Am. Heart J. **29**:697, 1945.
37. Grant, R. P.: The Relationship of Unipolar Chest Leads to the Electrical Field of the Heart, Circulation **1**:878, 1950.
38. Simonson, E.: The Distribution of Cardiac Potentials Around the Chest in One Hundred and Three Normal Men, Circulation **6**:201, 1952.
39. Schmitt, O. H., Levine, R. B., and Simonson, E.: Electrocardiographic Mirror Pattern Studies, Am. Heart J. **45**:416 (I), 500 (II) and 655 (III), 1953.
40. Sodi-Pallares, D., Rodríguez, M. I., Chait, L. O., and Zuckermann, R.: The Activation of the Interventricular Septum, Am. Heart J. **41**:569, 1951.
41. Fowler, N. O., and Helm, R. A.: The Spatial QRS Loop in Right Ventricular Hypertrophy With Special Reference to the Initial Component, Circulation **7**:573, 1953.
42. Sodi-Pallares, D.: Nuevas bases de la electrocardiografía, Prensa Médica Mexicana, México, 1951.
43. Barbato, E. C. D.: Estudo electrocardiográfico da ativacao ventricular normal e patológica. (Sua importancia na interpretacao das chamadas curvas de hipertrofia). Tese de doutoramento. Faculdade de Medicina da Universidade de Sao Paulo, 1952.
44. Tranchesi, J., Peñaloza, D., Lion, M. F., and Cisneros, F.: The Three Main Vectors of the Ventricular Activation Process in the Normal Human Heart. III. Its Relationship With the Potential Variations at the Body Surface, (To be published).
45. Kossmann, C. E., Berger, A. R., Rather, B., Brumlik, J., Briller, S. A., and Donnelly, J. H.: Intracardiac and Intravascular Potentials Resulting From Electrical Activity of the Normal Human Heart, Circulation **2**:10, 1950.

A COMPARISON OF NEHB'S BIPOLAR CHEST LEADS AND THE STANDARD 12-LEAD ELECTROCARDIOGRAM IN CASES OF MYOCARDIAL INFARCTION

PINEY POLLOCK, M.D.

BROOKLYN, N. Y.

IN 1938, Nehb proposed a system of bipolar chest leads[1] which he found of value in localizing myocardial infarction, particularly that in the posterior wall. By placing the electrodes directly on the chest wall, he constructed what he referred to as the "small heart triangle." This triangle is connected like the limb triangle and differs only in its points of contact. The right arm terminal is placed at the junction of the second right rib with the sternum; the left arm terminal is placed at the level of the apex beat, but in the posterior axillary line, and the left leg terminal is at the apex. Lead D (Dorsal) then corresponds to Lead I and records the electrical potential of the posterior wall of the heart. Lead A (Anterior) corresponds to Lead II and registers the electrical potential of the anterior wall and Lead J (Inferior) corresponds to Lead III, showing changes at the diaphragmatic surface of the heart.

Nehb found that many posterior wall infarcts showed changes earlier in Lead D than in the standard Leads II and III and that Leads A and J were generally superior to Lead I in the detection of anterior wall infarcts.[1] Further work by other German investigators supported this view.[2] Grewin in his excellent review of supplementary leads in clinical electrocardiography[3] supports the value of the Nehb system, and Lepeschkin states that Lead D is especially important in posterior infarction.[4]

Because of these interesting claims it was felt worthwhile to explore the possibilities of the Nehb system and compare it to the routine 12-lead electrocardiogram.

METHODS AND TECHNIC

Most of the papers reviewed were rather nebulous as to the normal range for the D, A, and J patterns. It was therefore deemed necessary to establish this before commencing the investigation. Fifty normal medical students between the ages of twenty and thirty were therefore studied. A complete 12-lead electrocardiogram was first done followed by V_7 and the D, A, and J leads. In those cases where the apex beat was not felt the fifth intercostal space in the midclavicular line was used. All the subjects were in the recumbent

From the State University of New York College of Medicine, at New York City, Brooklyn, N. Y.
At present: Research Assistant in Medicine, Mount Sinai Hospital, New York, N.Y.
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position when the tracings were made. Thirty consecutive patients admitted to the wards with a classical history of myocardial infarction were then studied, usually within four days of admission. Again a 12-lead electrocardiogram was first done, followed by V_7 and the D, A, and J leads. Suction cup electrodes were used on the chest for the Nehb leads and were placed on the points described previously. The lead selector of the electrocardiograph was then moved through Leads I, II, and III, and Leads D, A, and J, respectively, were inscribed.

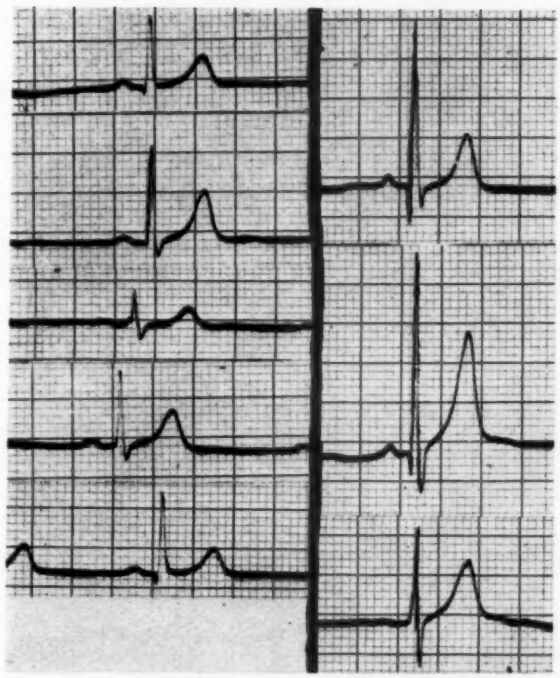

Fig. 1.—A normal young man. Leads I, II, III, aV_F, and V_7, from top to bottom on the left, and Leads D, A, and J on the right. All traces made with sensitivity of 10 mm./mv.

RESULTS

The study of the fifty normal subjects revealed the following:

Lead D.—A small Q wave was invariably present; the Q/R ratio in the majority of cases was below 20 per cent. Two cases (4 per cent) showed a Q wave above 33⅓ per cent and eight cases (16 per cent) presented a Q between 25 and 33 per cent. The R wave was usually quite prominent, and a small S wave was often present. The S-T was isoelectric in all cases, and the T wave was upright except in two cases (4 per cent).

Lead A.—A small Q wave often was present, and usually a very high R wave. A definite S wave was present in the majority of cases. The S-T segment was isoelectric, and a high T wave was almost always present.

Lead J.—No Q wave was present in this lead, and a moderate R wave was usually followed by deep S wave, sometimes equal to the R wave. The S-T segment was isoelectric and the T wave upright in all cases (Fig. 1).

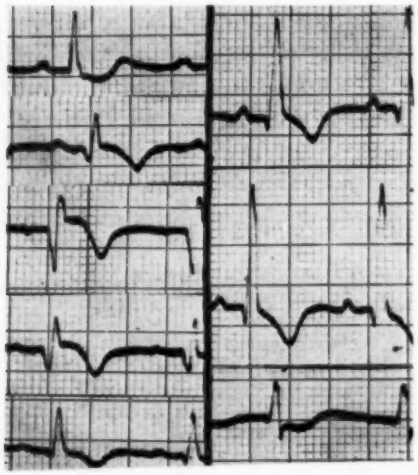

Fig. 2.—The leads as in Fig. 1, but from a 70-year-old woman with a fresh posterior wall infarction. Deep Q waves in Leads III and aV_F, with high S-T segments. Nehb's leads show only inverted T waves.

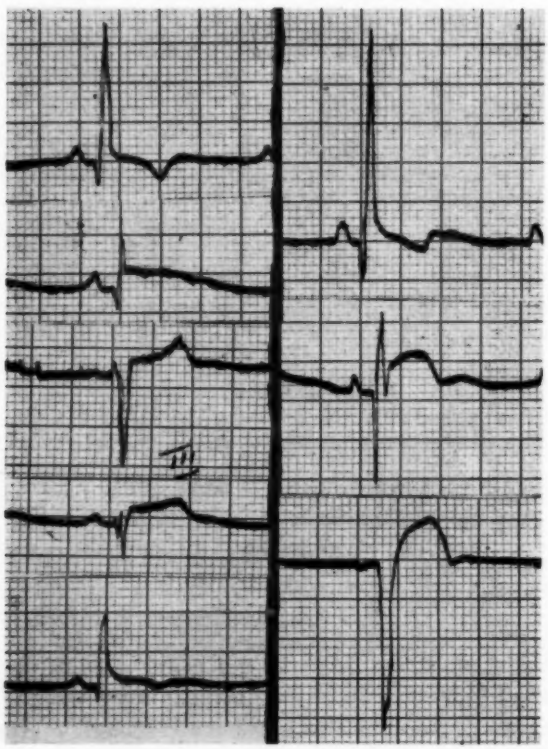

Fig. 3.—The leads as in Figs. 1 and 2, but from a 68-year-old man with a recent anterior wall infarction and left-axis deviation. Q wave and S-T segment displacement far more marked in Lead A than in the standard limb leads, but less than in V_2 to V_5.

The routine 12-lead electrocardiogram revealed that the thirty cases with the history of infarction had a fairly even distribution; fourteen cases presented as classical posterior wall infarcts; thirteen as anterior wall infarcts; two cases had completely normal electrocardiograms, and one case on repeated tracings showed progressive inversion of the T waves.

The bipolar chest leads were disappointing. The D lead, which according to its proponents should with greater frequency reflect posterior wall infarcts, showed an unequivocal infarction pattern in only six of the fourteen cases, five were suggestive (Fig. 2), and four were completely normal. It was interesting to note that in all cases where D was strongly positive, Lead V_7 was abnormal, but less strikingly so than the D lead.

The thirteen cases of anterior wall infarct showed up equally well on the bipolar chest leads, A or J or both (Fig. 3). In comparing Leads A and J with Lead I alone, however, it was observed that the former were more strikingly altered. In only one case was the Lead I unequivocally positive for anterior infarction, and in the twelve remaining cases the pattern was abnormal but not diagnostic. The unipolar precordial leads, however, were definitely diagnostic for all thirteen cases.

DISCUSSION

It is apparent that our results are inconsistent with those reported on the value of the bipolar chest leads. It appears that Lead D will only reflect posterior wall infarcts if the process has extended laterally to involve V_7. Lead D also records anterolateral infarctions if changes appear in V_7. Lead D therefore merely replaces V_7. In our series, Leads II, III, and aV_F were generally more reliable and consistent than was Nehb's Lead D in detecting posterior wall infarcts. Leads A and J on the other hand detected anterior wall infarcts as consistently and accurately as the precordial leads. These leads are vastly superior to Lead I of the standard leads in revealing such lesions. We must conclude that Nehb's system, while far superior to the limb leads in detecting anterior infarcts, is generally of much less value than the routine 12-lead electrocardiogram.

CONCLUSIONS

1. A review of the bipolar chest leads is presented and a comparison made to the twelve lead electrocardiogram, in fifty normal subjects and thirty cases of recent infarction.
2. No infarctions evident in Leads D, A, and J were missed in the 12-lead records.
3. The relation of changes revealed by these technics are discussed.

REFERENCES

1. Nehb, W.: Zur Standardisiesung Der Brustwandubleitungen Des Elektrokardiogramms, Klin. Wchnschr. **17**:1807, 1938.
2. Laurentius, P., and Bülow, S. U.: Der Diagnostische Wert Der DAJ—Ableitung Nach Nehb im Vergleich Zur Wilson—Und Extremitäten—Ableitung Bei Herzinfarkten, Klin. Wchnschr. **31**:612, 1953.
3. Grewin, K. E.: Some Supplementary Leads in Clinical Electrocardiography, Acta. med. scandinav. (supp. 130), 1948.
4. Lepeschkin, E.: Modern Electrocardiography, 1950, Baltimore, Williams & Wilkins Company.

THE BALLISTOCARDIOGRAM AND THE BLOCKAGE OF CIRCULATION THROUGH LIGATURE OF BOTH VENAE CAVAE

PEDRO COSSIO, M.D., JULIO A. BERRETA, M.D., AND HECTOR E. MOSSO, M.D.*

BUENOS AIRES, ARGENTINA

EXPERIMENTAL work in dogs was carried out in order to give a basis to the ballistocardiogram. In the first instance, myocardial damage was induced by ligature of a coronary artery or by myocardial cauterization. This was followed constantly by ballistocardiographic alterations.[1] This paper deals with the elimination of the blood circulation factor in the ballistocardiogram.

METHOD

Twelve dogs, varying in weight, were anesthetized with intraperitoneal Nembutal. The blockage of the circulation was performed by ligature of both venae cavae and azygos veins, following the technique described in a previous paper. It was known that cardiac activity is not impaired up to eight minutes after the ligatures are placed.[2,3]

An electromagnetic ballistocardiograph connected to Siemens electrocardiograph was used, standardized so that 1 millivolt would correspond to a displacement of 1 cm. The dogs were placed on their backs with the ballistocardiograph on their hind legs. The tracings were registered before and after the thoracic opening and every minute after the operation was performed, until standstill of the heart ensued (ordinally within eight to twelve minutes).[2,3]

In nine instances the ligatures were permanent, while in three the blockage was intermittent. Blocking and unblocking were done two and three times every two or three minutes.

RESULTS

The ballistocardiograms prior to thoracic opening were polymorphic in their general appearance and height as described in the first experience, but constant in the same animal and therefore allowing further comparisons. After the thoracotomy and the dissection of the veins, the volume of the tracings increased with stronger and faster heart beats as easily observed.

After the ligatures in six dogs, the height of the tracings increased immediately, running parallel with the height and speed of each heart beat in the first

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*Dr. I. Perianes performed the surgical part of the work.

five or six minutes. The height and speed of the heart beat were so marked that the entire body of the animal was beating. This phenomenon was noticeable even on the operating table. At this moment, the heart beat "in vacuo", that is to say, without any blood entering or leaving it. The blood pressure was zero and the opening of the carotid artery did not give a drop of blood. The deflections of the ballistocardiogram were easily detected and at times more clearly defined than before.

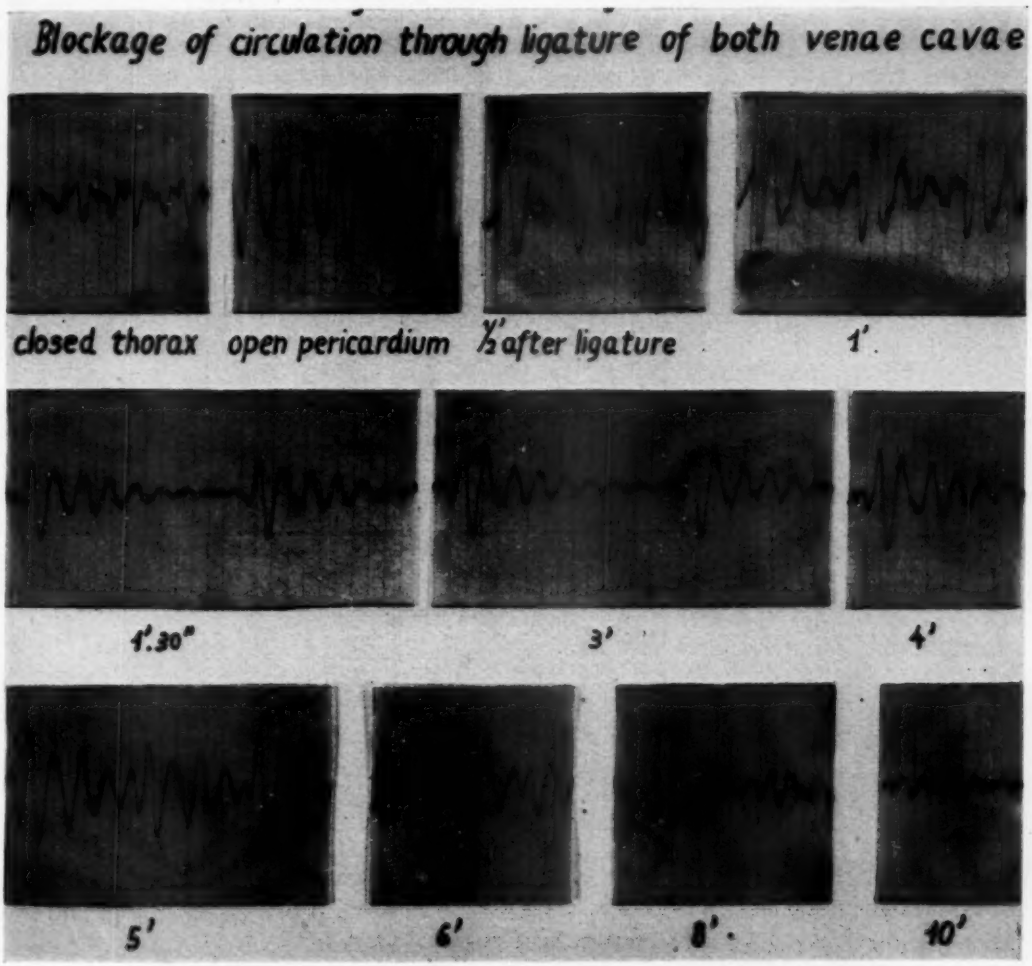

Fig. 1.—Dog ballistocardiogram.

Seven minutes after the interruption of circulation the heart beat was remarkably weaker, and the height of the deflections diminished; finally, after a few seconds, they could not be registered (Fig. 1).

In the other three dogs, the ballistocardiogram showed small and irregular deflections from the start, coinciding with smaller and slower heart beats which were not transmitted to the thoracoabdominal wall of the animal (Fig. 2). The heart stopped or ventricular fibrillation appeared much sooner in this group of animals.

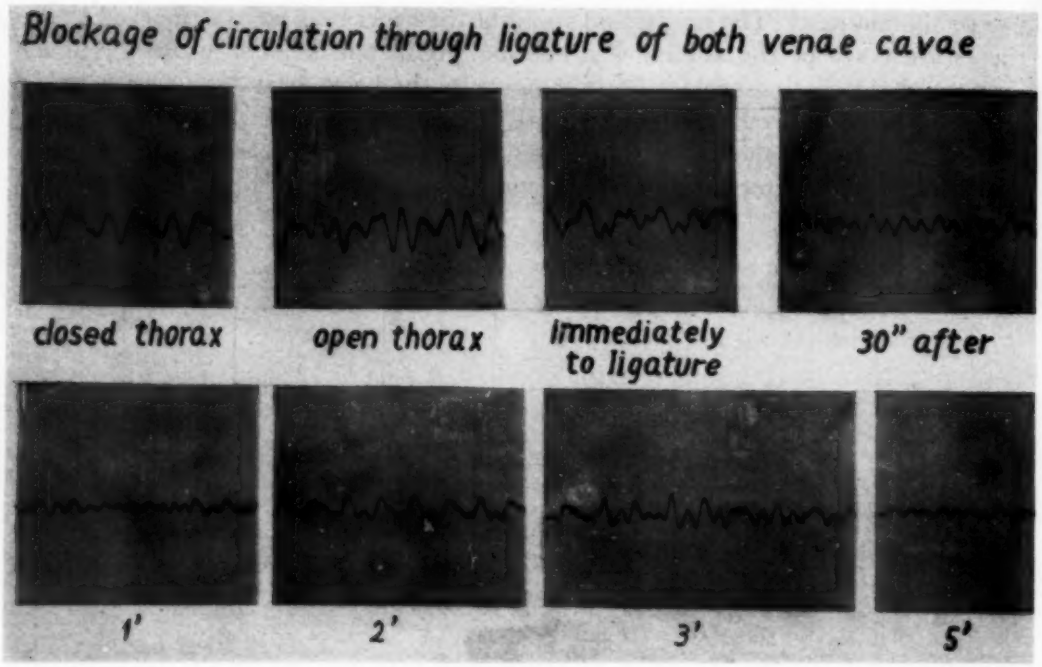

Fig. 2.—Dog ballistocardiogram.

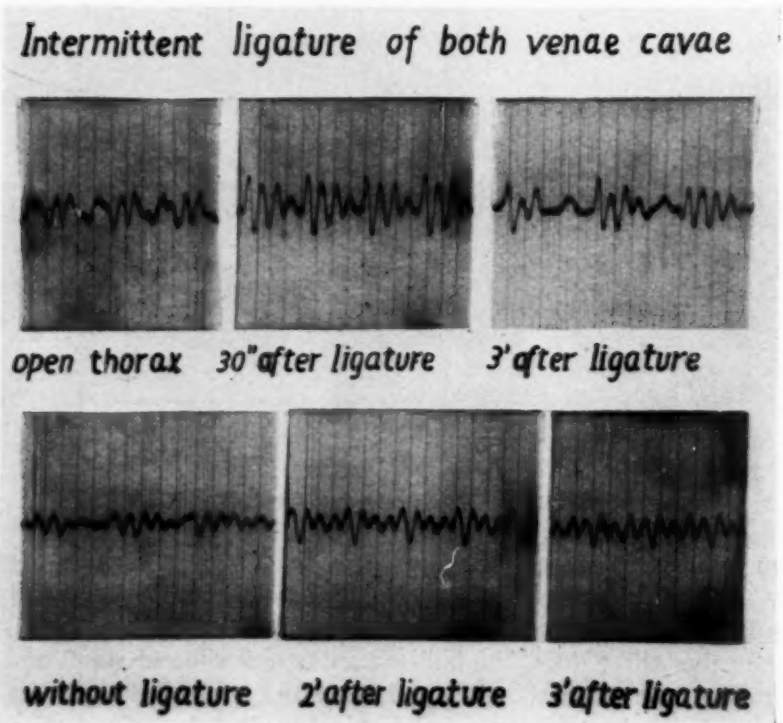

Fig. 3.—Dog ballistocardiogram.

In the animals in which the ligature was intermittent, the deflections were easily registered, and in two of them, increased as the ligature was placed and decreased as it was removed (Fig. 3).

DISCUSSION

These experiments have confirmed our previous report on the great polymorphism of the ballistocardiogram in the several dogs. This is of course a great difficulty for the correct evaluation of ballistocardiographic records of different animals, but successive tracings on the same animal can be compared to those obtained prior and after the experiments.

The importance of the heart beat in the origin of the ballistocardiogram is stressed by this experiment. The other factors (systolic output, arterial elasticity, length and diameter of the aorta, peripheral resistances) are not essential. The shape of the tracing is registered the same, even when the blood supply of the heart is stopped, and there is no incoming or outgoing blood. So all these factors are secondary and would influence the tracing only through the changes they may determine in the movements originated by the heart beat. As for the meaning of each deflection we must bear in mind that notwithstanding the blockage of circulation, the general pattern and number of deflections are not altered, just as if the heart were still expelling blood. Therefore, the extracardiac origin of certain deflections (those due to the pressure wave of the blood that circulates in the arterial tree)[4] is of less importance.

In our opinion, it should be admitted that there are only one or two early essential systolic deflections and that the others are pendular secondary waves. The latter are caused by a vibration movement that dies out progressively, and they could be influenced by forces originated in the circulation of blood.

The increased height of the ballistocardiographic deflections after the ligature of both venae cavae may be attributed to the elimination of the resistance to circulation. The heart is beating then without the resistance which in normal circumstances is generated by the movement of the liquid mass. The heart beats were of such intensity and volume that they irradiated to the whole surface of the body and at times even to the operating table, even with the cardiac ischemia due to the blockage of circulation. It is common knowledge that myocardial ischemia without eliminating peripheral resistances originates hypokynesia of the myocardium registered graphically by Wiggers and associates[5,6] and more recently Prinzmetal and associates[7] with ultra rapid films. This would also be the explanation for the 35 per cent of cases in which the volume of the ballistocardiogram did not increase but even decreased after the ligature. The small and slow heart action did not induce a beat even in the epigastric region and would be explained by hypokinesis of the myocardium, in spite of the elimination of the resistances. In those conditions, we came to the conclusion that in dogs with marked heart beat after the ligature of the caval veins, the ballistocardiographic deflections were of large volume and well defined, and that beats of smaller volume generated smaller and less defined deflections.

The ballistocardiogram is therefore fundamentally caused by the heart action and may be due only in a small measure to the circulation of the blood.

On the other hand, we believe "sensu strictu" that there are only one or two principal systolic deflections. The other deflections represent pendular movements of the body dying out, as proved graphically by the tracings registered during bradycardia. In this case, the lengthening of diastole favors the registration of those movements (Fig. 1), which could be influenced by forces originated in the circulation of blood.

SUMMARY

We have analyzed in twelve dogs the action on the ballistocardiogram of the blockage of the circulation through ligature of both venae cavae. In nine instances the ligature was permanent, while in three the blockage was intermittent, blocking and unblocking two and three times every two or three minutes.

The ballistocardiograms prior to thoracic opening were polymorphic in their general appearance and height, but constant in the same animal, and therefore allowed further comparisons. After the ligatures in six dogs, the height of the tracing increased immediately, running parallel with the height and speed of each heart beat. The ballistocardiographic deflections were very easily detected and at times more clearly defined than before, yet the heart was beating without blood. In the other three dogs, the ballistocardiograms showed small and irregular deflections from the start.

In the animals in which the ligature was intermittent, the deflections were easily registered, and in two of them increased as the ligature was placed and decreased as it was removed.

The ballistocardiogram is therefore fundamentally caused by the heart action and may be due in a small measure to the circulation of blood and peripheral factors.

The increased height of the ballistocardiographic deflections after the ligature of both venae cavae (the shape remains unchanged) may be attributed to the elimination of the resistance of circulation.

REFERENCES

1. Cossio, P., Berreta, J. A., Mosso, H. E., and Perianes, I.: El balistocardiograma en la agresión miocárdica experimental, Rev. Arg. de Card. **20**:85, 1953.
2. Perianes, I., and Berreta, J. A.: Interrupción de la circulación. Mantenimiento artificial de la circulación encefálica y coronaria, Bol. y Trabajos de la Sociedad Arg. de Cirujanos, Año XI; Sesión del 5 de junio de 1950.
3. Perianes, I., and Berreta, J. A.: Efectos de la interrupción de la circulación con o sin perfusión del cabo cefálico de am bas carótidas, Medicina **10**:337, 1950.
4. Dock, W., Mandelbaum, H., and Mandelbaum, R. A.: Ballistocardiography, St. Louis, 1953, The C. V. Mosby Co.
5. Tenant, R., and Wiggers, C. G.: The Effect of Coronary Occlusion on Myocardial Contraction, Am. J. Physiol. **112**:351, 1935.
6. Wiggers, C. J.: Physiology in Health and Disease, ed. 5, Philadelphia, 1950, Lea & Febiger.
7. Prinzmetal, M., Schwartz, L., Corday, E., Spritzler, R., Berman, H., and Kruger, H. E.: Studies on the Coronary Circulation. Loss of Myocardial Contractility After Coronary Artery Occlusion, Ann. Int. Med. **31**:429, 1949.

THE TELECARDIOGRAM

F. A. L. Mathewson, M.D., and H. Jackh, M.D.

Winnipeg, Canada

THREE articles[1-3] appeared recently in the medical literature describing the successful transmission of electrocardiographic signals over standard telephone circuits. The authors point out that this provides a method whereby electrocardiograms recorded in rural areas may be interpreted without delay in large centers by persons specially trained in electrocardiography.

Without in any way detracting from the value of these communications it seems appropriate that some reference should be made to William Einthoven's original contribution to this subject. In 1905, Einthoven delivered two papers, one before the general assembly of the Société Hollandaise des Sciences and the other at a meeting of the Société de physique, de medicine et de chirurgie, which were condensed and published in 1906.[4] In this paper he gives a general description of the string galvanometer including details of the coordinates used today in measuring time and voltage and a brief account of the derivation of the standard limb leads. He then describes and names the various deflections of the normal electrocardiogram. The need for studying the electrocardiograms of patients with heart disease was recognized but to do this he had first to overcome the technical problem of obtaining electrocardiograms on inpatients when his nonportable galvanometer was situated in the physiological laboratory which stood some distance from the hospital. How he surmounted this difficulty is told in the following free translation of selected paragraphs from his paper.

19.* "It might naturally be expected that a diseased heart would trace an electrocardiogram of different form than a healthy heart. This supposition has been confirmed directly by a few preliminary observations made in my laboratory. But the number of cases so examined was of necessity quite limited in view of the difficulties involved in transporting patients, particularly when severely ill, to the physiological laboratory. However, it was imperative that the number of such observations be increased; because any extensive research into the diseases of the heart must necessarily be based upon a large number of cases.

20. It was then that Professor Bosscha suggested the idea of linking the Hospital of Leiden University by conducting wires to the Physiological Laboratory where the almost immovable galvanometer is located. This would make it possible to examine patients in the hospital with the galvanometer in the laboratory.

From the R.C.A.F. Cardiovascular Research Laboratory Department of Medicine, Faculty of Medicine, University of Manitoba, Winnipeg, Canada.

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*The numbers refer to the original paragraphs.

21. To establish whether this idea was practical, an experiment was necessary and for this purpose Professor Place offered to devote the subsidy which La Société Hollandaise des Sciences designates for Physiological research. Mr. Place's offer was accepted and the experiment was carried out.

22. At first sight the question of the electrical connections appears quite simple. Since electric currents daily bring us information by telegraph from all parts of the world, why should not the currents originating in the heart be conducted from the hospital to the laboratory? Actually, the principle is perfectly sound, although we ran into a number of practical difficulties.

23. We availed ourselves of a circuit of the Leiden Telephone System, installed perfectly by Mr. Ribbink and Mr. Yan Bork. The wires of this system run partly underground, partly overhead. While the underground wires manufactured by the firm Felton et Guilleaume of Muhlheim-on-Rhine left nothing to be desired it was realized that the part of the circuit, running above ground, could not be used for our investigations.

24. Overhead wires are never absolutely motionless. They constantly undergo slight oscillatory movements which bring them closer together or draw them apart at irregular intervals. Thus the circuit is affected to a varying degree by the lines of force of the earth's magnetic field, creating currents which make the galvanometer unstable.

25. As it was impractical to run the entire circuit underground, we connected the terminals of the underground wires to insulated wires, twisted together so as to maintain a constant relation to each other, and surrounded them with a lead cable covering. This lead cable, heavy and flexible, could not be strung in the air so we suspended it to a steel cable. Even when this cable was blown about by the wind, there occurred no alteration of the galvanometer reading. Thus we overcame one of our original difficulties.

26. We met further difficulties involving imperfect insulation and reciprocal induction of the wires of the telephone system. Each time a subscriber receives a call, rather intensive currents are set up in the system and, if the wires are not perfectly insulated, these currents pass from one wire to the other causing the readings of the galvanometer once more to become unstable.

27. We took great pains to insulate the wires to the galvanometer as perfectly as possible. The replacement of the bare aerial terminal wires which were necessarily poorly insulated at the points of support, by the lead cables previously mentioned, constituted an important improvement. Moreover, the use of this lead cable enabled us without danger to dispense with the usual lightning arresters which are always a source of error; all that now remained to be done was to ground the lead cable. The insulation of the lead cables was always quite satisfactory but the junction of the underground and aerial wires is, even today, a weak spot. During dry weather the resistance here attains 2,000 to 3,000 megohms, but on rainy days it may fall to 10 megohms or less.

28. The mutual induction, especially troublesome in the lead-in wires when strung parallel and unprotected, has also been markedly reduced by the use of lead cables.

29. Let us now connect one end of the galvanometer string to one of the conducting wires linking the laboratory with the hospital, and ground the other end of the string. Under these conditions the galvanometer is affected by stray currents produced in the telephone system whenever a subscriber gets a call.

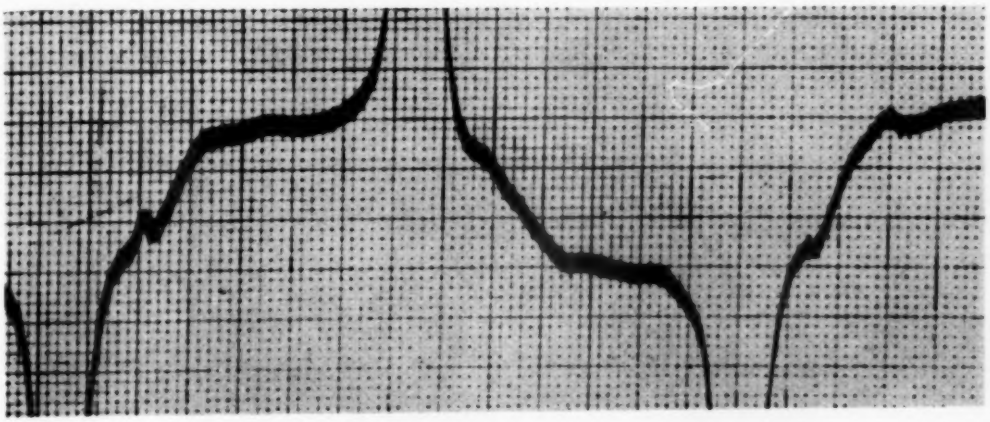

Fig. 1.—Absc. 1 mm. = 0.001 sec.; ordin. 1 mm. = 10^{-7} amp.

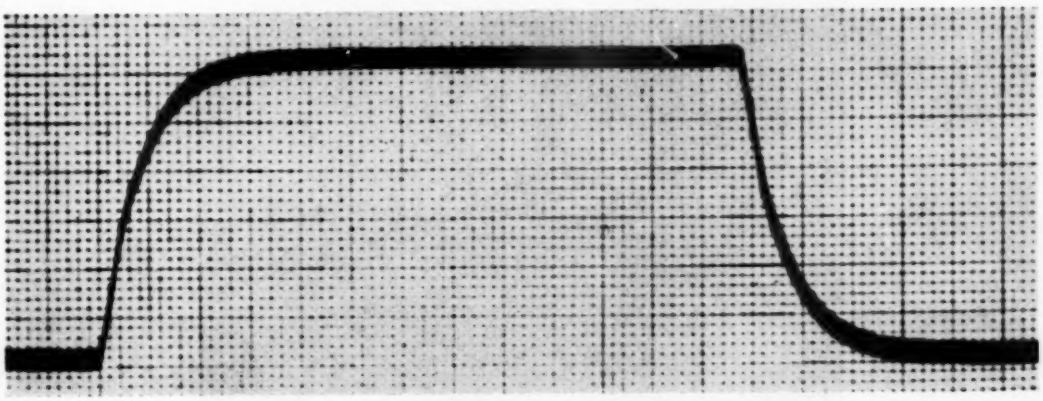

Fig. 2.—Absc. 1 mm. = 0.001 sec.; ordin. 1 mm. = 10^{-4} volts.

These stray currents are caused by imperfect insulation and by the mutual induction which still exists; they are sufficiently powerful to deflect the string picture entirely out of the field. However these currents may be reduced considerably by connecting each pole of the galvanometer to one of the wires linking the laboratory with the hospital thus eliminating the ground connection. But even under these circumstances we still observed vibrations of the string as long as the circuit was interrupted at the hospital itself or closed by a very high resistance. They ceased only when the circuit was closed at that point, either directly or by switching in a relatively weak resistance, such as that of the human body (varying from 1,000 to 2,000 ohms in our experiments). Actually, these are the exact practical conditions under which we operate.

30. In Fig. 1 (Einthoven's Fig. 12)[3] we see a photogram which was obtained by deliberately grounding one of the poles of the galvanometer string. The sensitivity of the galvanometer was about five times less than that used in taking the usual electrocardiograms. However, we note that the string picture is thrown completely out of the field by a telephone call of a subscriber. The speed of the plate movement was 1 mm. per sec., meaning that 1 mm. under the abscissa corresponds to 0.001 sec., while 1 mm. under the ordinate represents a current of 10^{-7} amp.

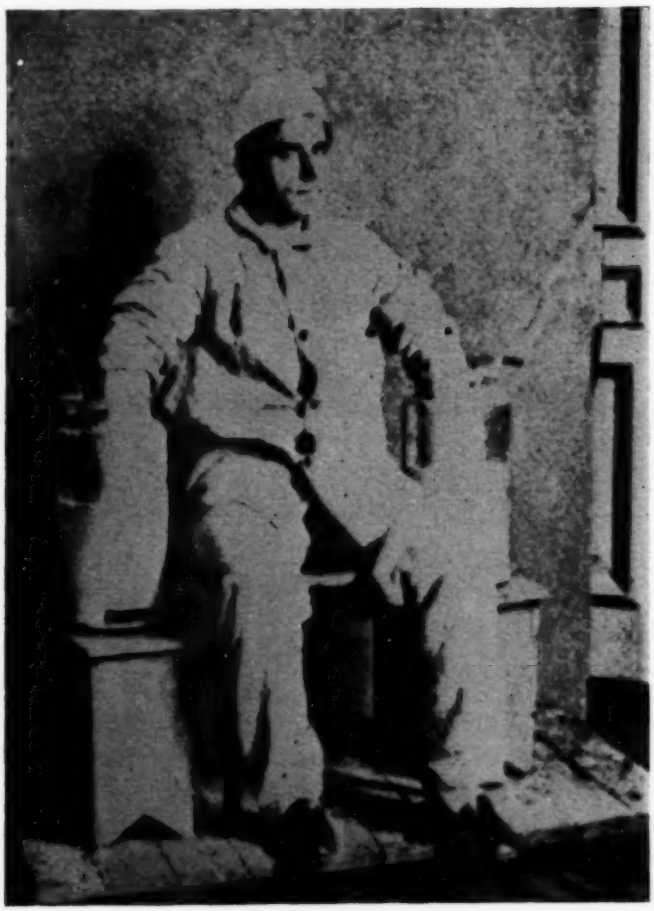

Fig. 3.

31. Fig. 2 (Einthoven's Fig. 13), however, represents a print obtained under the same favorable conditions as we usually maintain in recording the hospital electrocardiograms, i.e., without any ground connection and by linking the wires with the hospital by means of a resistance of 1,500 ohms. We see that there is no vibration whatever; the string remains absolutely motionless.

At a certain point in the circuit we suddenly switched in a constant potential difference of 3 millivolts. This was answered by the string with a deflection of 30 mm. Consequently 1 mm. corresponds to 10^{-4} volts which is the sensitivity regularly applied in registering electrocardiograms.

32. During the tracing, the photographic plate moved at a speed of 1 mm. per sec. Therefore 1 mm. in the horizontal direction once more corresponds to 0.001 sec. We note on the tracing that the deflection ends almost completely in 10 to 12 mm., i.e., in 1 to 1.2 hundredths of a second. This duration of the deflection differs very little, at most by some ten thousandths of a second, from that obtained when the hospital wires are not used; in any case, the difference is so slight that it may be overlooked in all the following experiments. There is a question, however, as to what the duration of the deflection would be, if the distance between laboratory and hospital was greatly increased.

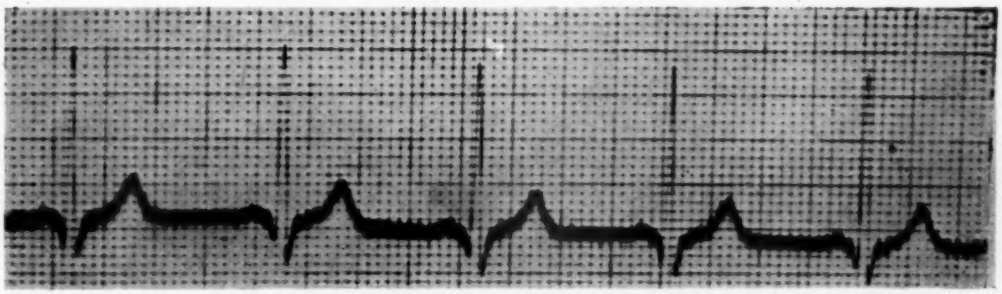

Fig. 4.—Recording from both hands.

33. As the conducting wires are lengthened their self-induction, resistance, and capacity are similarly increased, thereby setting a limit on the distance at which successful transmission can be made. The wires between the laboratory and the hospital are approximately 1 mile long. Their self-induction is negligible, while their resistance is 106 ohms and their capacity 0.075 μf. From this it may be calculated that wires of much greater length could be used successfully and that it would be possible to connect Leiden with The Hague or Haarlem: I believe that a practically usable connection could even be established between Leiden and Rotterdam or between Leiden and Amsterdam.

34. Let us now go over to the hospital and watch a patient having an electrocardiogram recorded. He is comfortably seated on a chair and has each hand immersed in a large jar to which is attached one of the wires connected to the laboratory [Fig. 3] (Einthoven's Fig. 14); or again he holds one hand in one of the jars and one foot in the other. The electrocardiogram, in this case actually a *telecardiogram*, is traced in the laboratory. In this way the operation is practical and simple, and it has the advantage of being quicker in comparison with the procedure used where the patient is beside the galvanometer. As a matter of fact, the operations involved in the experiment are now distributed among two groups of persons, each group having freedom of movement in its own location without interfering with the other.

35. Fig. 4 (Einthoven's Fig. 16) is a reproduction of the first telecardiogram which we registered; it is that of a healthy and vigorous man and the current came from both hands. It is completely identical to the tracing taken on the same subject in the laboratory, close to the galvanometer. The five summits, the first of which, P, is caused by the auricular systole and the four others, Q, R, S and T by the ventricular systole, are in both cases identical in form and height. With this subject, summit R is particularly high and corresponds to a potential difference of 2 millivolts".

Thus the first electrocardiogram was sent over the wires of a telephone system nearly fifty years ago, and it was by this means that the first studies of the electrocardiograms of persons with heart disease were made possible. Using the string galvanometer with its dependence upon circuits of low resistance, Einthoven recorded his "télécardiogramme" under circumstances which today are largely circumvented by the use of other methods of recording.

The authors gratefully acknowledge the contributions of Mr. H. L. Caron and others who so cheerfully assisted in the translation.

REFERENCES

1. Kanatsoulis, A.: Le Tele-electrocardiographe, Presse méd. **59**:458, 1951.
2. Dimond, E. Gray, and Berry, F. M.: Transmission of Electrocardiographic Signals Over Telephone Circuits, AM. HEART J. **46**:906, 1953.
3. Rahm, W. E., Barmore, J. L., and Dunn, F. L.: Electrocardiographic Transmission Over Standard Telephone Lines, Nebraska M. J. **37**:222, 1952.
4. Einthoven, W.: Le Telecardiogramme, Arch. internat. physiol. **4**:132, 1906.

Clinical Reports

MYOCARDIAL INFARCTION IN PREGNANCY

NICHOLAS A. ANTONIUS, M.D., PATRICK A. IZZO, M.D.,
GERALD W. HAYES, M.D., AND CHARLES R. WALSH, M.D.

NEWARK, N. J.

MYOCARDIAL infarction in pregnancy is extremely rare. In fact, coronary artery disease is rare in women during their childbearing period. Dublin[1] found the death rate from this disease in women to be about 3.5 per 100,000 during the ages of 35 to 44 years.

The purpose of this paper is to review the reports in the literature of myocardial infarction during pregnancy, to report an additional case, and to discuss the problems encountered in management.

Up to the present time there appear to be seven cases reported of myocardial infarction occurring during pregnancy. A few additional cases have appeared in the literature, but insufficient evidence is presented in these cases to be reasonably sure that infarction had occurred. The seven cases reported are summarized in Table I.

CASE REPORT

R. W., a 36-year-old white woman was 7 months pregnant when admitted to St. Michael's Hospital at 5:00 A.M. on Nov. 30, 1953, with the chief complaint of having been awakened at 3:00 A.M. by severe and squeezing retrosternal pain which radiated to the right shoulder and the right side of the neck. The pain was accompanied by dyspnea, cold sweats, nausea, and vomiting.

The past history was irrelevant except for an unexplained spontaneous abortion of nonviable twins in August, 1952. No history of hypertension or symptoms of angina could be obtained. The prenatal period during the present pregnancy was uneventful.

Physical examination on admission revealed a well-developed white female having chest pain accompanied by vomiting and preferring to assume the sitting position. The pulse rate was 60 per minute with regular rhythm and respirations at 20 per minute. The blood pressure was 144/98 mm. Hg. There was pallor of the skin but no cyanosis. The heart sounds were well defined and appeared normal. The lungs were clear to auscultation and percussion. The abdomen was soft and the uterus extended 4 cm. above the umbilicus. The liver was not palpable. There was no ankle edema.

The hemogram on admission showed 4,210,000 red blood cells, with 77 per cent hemoglobin. There were 34,050 white blood cells with 92 per cent segmented polymorphonuclear leukocytes, 6 per cent stab cells and 2 per cent lymphocytes. Sedimentation rate was 79 mm. per hour (Wintrobe). Urinalysis revealed a urine with light amber color with specific gravity of 1.024 and 2+ albumin. Blood chemistry showed a blood sugar of 80 mg. per cent, urea nitrogen of 13.6 mg.

From the Departments of Cardiology and Obstetrics, St. Michael's Hospital, Newark, N. J.
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TABLE I

	YEAR	AUTHOR	AGE (YR.)	B.P.	ECG	COMMENT
1.	1922	Katz[2]	33		+	Death occurred at onset of labor. Autopsy revealed coronary atherosclerosis with myocardial infarction.
2.	1935	Reis and Frankenthal[3]	45	210/140	+	Infarction occurred at term with myocardial failure. Had forceps delivery and survived.
3.	1937	White et al.[4]	22	115/70	+	Infarction occurred at 2 mo. Had forceps delivery at term and survived.
4.	1938	Jensen[5]	39	132/86	+	Infarction occurred at 5 mo. Had forceps delivery at term and survived.
5.	1941	Hamilton and Thomson[6]		186/110	+	Infarction occurred at 2 mo. Had hysterotomy at 3 mo. and survived.
6.	1950	Goldberger and Pokress[7]	37		+	Infarction occurred at 4 mo. with myocardial failure. Had normal delivery at 7 mo. Also suffered from tertiary syphilis and rheumatic heart disease, survived.
7.	1952	Mendelson[8]	42	210/120	+	Infarction occurred at 5 mo. Underwent Cesarean section at 39 weeks and survived.
8.	1954	Antonius		144/98	+	Infarction at 7 mo. Had forceps delivery at 7 mo. and survived.

per cent, uric acid of 4 mg. per cent and a cholesterol of 130 mg. per cent. The Wassermann reaction was negative. The electrocardiogram shown in Fig. 1 was taken a few hours after admission to the hospital and revealed changes indicative of acute anterior wall myocardial infarction.

Following admission to the hospital the retrosternal pain persisted in spite of the usual doses of morphine. About 5 hours after admission while the patient was experiencing substernal pain and dyspnea, examination revealed the presence of bilateral basal râles in the lungs and a pericardial friction rub at the third intercostal space to the left of the sternum. Digitalization was withheld and treatment consisted of the use of mercurial diuretics.

On the evening of admission the patient developed uterine contractions. Labor progressed slowly and at 5:00 P.M. on the day following admission successful delivery of a 2 pound, 14 ounces, healthy premature male infant was accomplished with the use of forceps and episiotomy. Anesthesia consisted only of local infiltration of the perineum with 1 per cent procaine hydrochloride. Oxygen inhalation was given by mask during the course of delivery.

The patient's postpartum course was uneventful. The physical signs of cardiac failure gradually subsided. The pericardial friction rub persisted for 6 days and then disappeared. In Fig. 2 is shown the electrocardiogram taken 3 weeks after the onset of myocardial infarction. The progressive changes are typical of a recent and healing anterior wall infarction.

The patient was discharged asymptomatic on the thirtieth hospital day. Up to the present time both mother and infant are well.

COMMENT

This case presents some interesting medical and obstetrical problems. Numerous investigative studies indicate that the circulatory burden in pregnancy starts early in the second trimester, gradually rises to a peak in the beginning of the third trimester, and returns to normal at term. The increase in cardiac output has been variously stated to be from 27 to 50 per cent and is closely associated with augmented blood volume.[9,10]

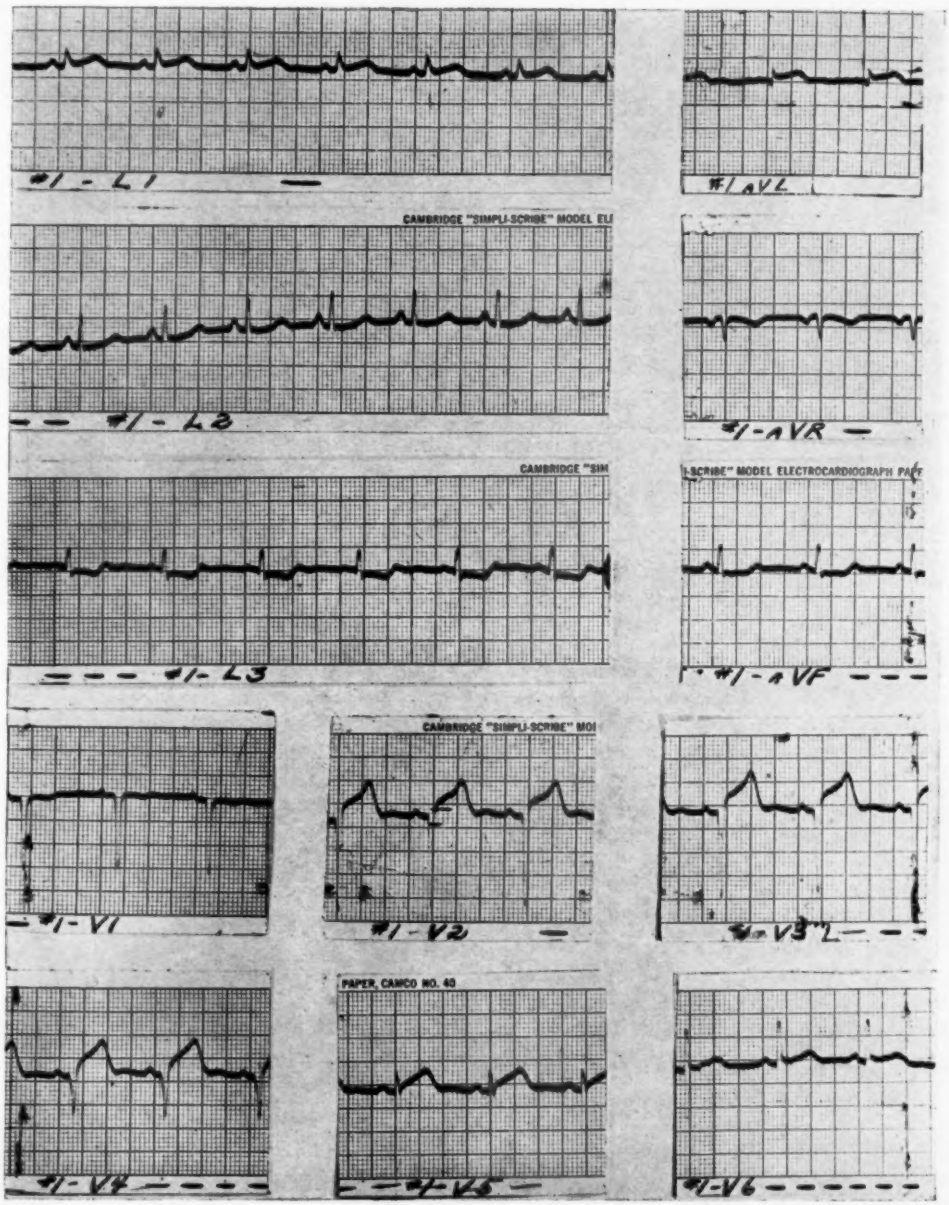

Fig. 1.—Tracing taken on admission. RS-T elevation in Leads I, aV_L and V_2 through V_5. RS-T depression in Leads III and aV_F. Significant Q waves in V_1 through V_4. The changes are indicative of acute anterior-wall myocardial infarction.

Therefore, this case suffered from myocardial infarction close to the peak of the circulatory burden. A minimal degree of myocardial failure presented itself with dyspnea and bilateral basal râles shortly after the onset of infarction and disappeared as the infarction healed. During the 36 hours following infarction the patient suffered severe precordial pain which necessitated the liberal use of morphine. In spite of the use of this narcotic the premature infant exhibited no signs of respiratory depression at the time of delivery. The onset of labor within a relatively short time after infarction presented an alarming situation.

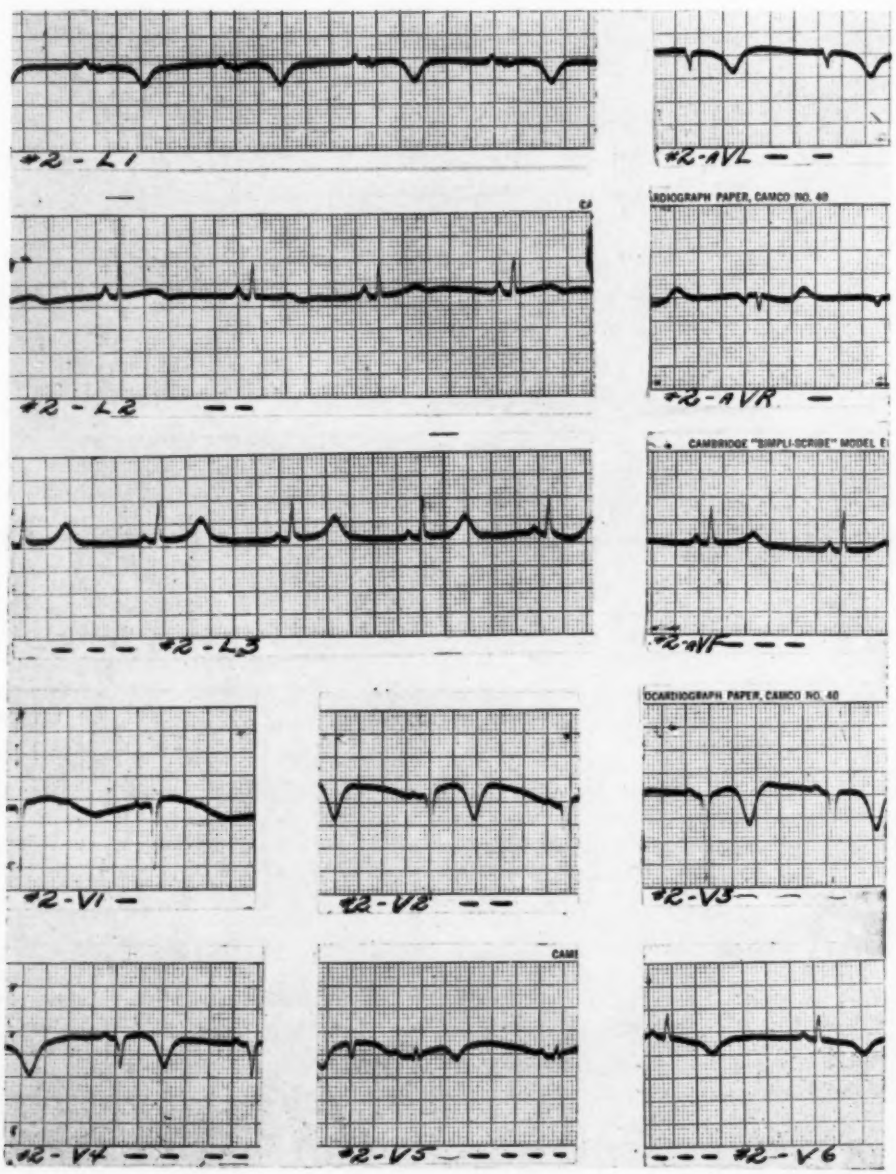

Fig. 2.—Tracing taken 3 weeks after admission. Subsequent T wave inversion in Leads I, aV_L, and V_2 through V_6. Significant Q waves in Leads I, aV_L, and V_2 through V_4. Decrease in amplitude of R_1. The changes are indicative of a healing anterior-wall myocardial infarction.

With conservative and careful management the burden of labor was well tolerated. The avoidance of general anesthesia was accomplished.

REVIEW OF CASES

Of the total eight cases reported only six cases had the blood pressure recorded. Of the six recorded, three cases or 50 per cent suffered from an associated hypertension. The mortality was one case or 16.5 per cent. The ages ranged from 22 to 45 years. The onset of infarction varied throughout the trimesters of pregnancy with three cases occurring at or close to term. The one death occurred at the onset of labor. Three cases exhibited signs of cardiac decompensation at the time of myocardial infarction but myocardial failure did not present itself after the healing of the infarct, regardless of the circulatory burden or physiologic load.

Five cases were delivered vaginally. In one case pregnancy was interrupted with a hysterotomy at 3 months and in one case Cesarean section was done at the thirty-ninth week of pregnancy.

All cases presented electrocardiographic or autopsy evidence of myocardial infarction. All other reports of probable infarction were excluded from this report if evidence was lacking to substantiate a diagnosis of myocardial infarction.

Management of Pregnancy and Delivery.—Myocardial infarction during pregnancy presents medical and obstetrical problems that require the close cooperation of both the internist and the obstetrician. Although, to date, the number of cases reported are few some valid conclusions can be drawn in an attempt to determine the proper management.

Interruption of pregnancy because of myocardial infarction is not warranted. Cesarean section, unless for obstetrical reasons, seems to have no place in the management of these cases. The peak of the circulatory burden is usually passed when Cesarean section would be used so nothing can be gained with the added risk of a surgical procedure.

The current use of anticoagulant drugs has reduced the mortality following myocardial infarction by decreasing the incidence of thromboembolic phenomena. These drugs traverse the placenta,[11] and hypoprothrombinemia with hemorrhage has been reported in the newborn.[12] Mendelson[8] reported the successful use of Dicumarol from the fifth to the seventh month of pregnancy following myocardial infarction. In this case a normal infant was born without any evidence of hemorrhagic manifestations. But the limited use of these drugs during pregnancy requires further trial for their proper evaluation. If anticoagulant drugs are to be administered to pregnant women, they must be used with caution, when term approaches, to avoid hemorrhage. The usual precautions must be exercised in the use of these drugs. It seems wise to discontinue therapy with the onset of labor and to administer vitamin K. The infant should be given vitamin K immediately after delivery and not allowed to nurse until the mother's prothrombin time returns to normal.

The management of delivery at term seems to be clear. The route of vaginal delivery with forceps is the choice. Cesarean section is not indicated unless for obstetrical reasons. The use of local or block anesthesia with avoidance of general anesthesia is recommended whenever possible.

SUMMARY

We have presented, with electrocardiograms, a case of a 36-year-old white woman who suffered from myocardial infarction during the seventh month of pregnancy. The onset of premature labor began the same day as the infarction occurred and presented some alarming problems which have been discussed.

Delivery was accomplished vaginally with forceps on the day following the onset of infarction. Both the mother and the premature infant survived and are well.

Seven cases of reported substantiated myocardial infarction occurring during pregnancy are reviewed. One case added by the authors brings the total to eight cases. The ages ranged from 22 to 45 years. A significant percentage of 50 per cent suffered from hypertension. There was one death with a mortality rate of 16.5 per cent. The onset of infarction in terms of months pregnant varied and offered no clue as to prognosis. Myocardial failure occurred in three cases and improved as the infarction healed. Five cases were delivered vaginally with the use of forceps. One case was delivered by Cesarean section at 39 weeks of pregnancy and in one case pregnancy was terminated at 3 months with hysterotomy because of hypertensive complications. Successful use of anticoagulant therapy in myocardial infarction during pregnancy appeared in one case.

The problem of myocardial infarction in pregnancy is presented. The management of these cases is discussed even though the number of recorded cases is small.

CONCLUSIONS

1. The incidence of myocardial infarction during pregnancy is extremely low. A significant percentage suffer from hypertension.
2. The management of myocardial infarction in pregnancy requires close cooperation between the internist and the obstetrician.
3. Interruption of pregnancy for this complication is not indicated.
4. A previous myocardial infarction does not contraindicate pregnancy. Pregnancy can be successfully completed following myocardial infarction.
5. Anticoagulant therapy may be used with caution prior to the onset of labor.
6. The choice of delivery at term is that of vaginal delivery with forceps.
7. Cesarean section should be limited to obstetrical indications.
8. Myocardial failure from cardiac infarction usually improves as the area of infarction heals. The current therapy of myocardial failure is indicated during the healing phase.

REFERENCES

1. Dublin, L. I.: In Levy, R. L. (editor): Diseases of the Coronary Arteries and Cardiac Pain, New York, 1936, The Macmillan Company.
2. Katz, H.: Arch. f. Gynak. **115**:283, 1922.
3. Reiss, R., and Frankenthal, L. E.: Am. J. Obst. & Gynec. **29**:44, 1935.
4. White, P. D., Glendy, R. E., and Gustafson, P.: J.A.M.A. **109**:863, 1937.
5. Jensen, J.: The Heart in Pregnancy, St. Louis, 1938, The C. V. Mosby Company.
6. Hamilton, B., and Thomason, K. J.: The Heart in Pregnancy and the Childbearing Age, Boston, 1941, Little, Brown and Company.
7. Goldberger, E., and Pokress, M. J.: New York State J. Med. **50**:95, 1950.
8. Mendelson, C. L.: Am. J. Obst. & Gynec. **63**:381, 1952.
9. Stander, H. J., and Cadden, J. F.: Am. J. Obst. & Gynec. **24**:13, 1932.
10. Hamilton, H. F.: J. Obst. & Gynaec. Brit. Emp. **61**:4, 1949.
11. Kraus, A. P.: J.A.M.A. **139**:758, 1949.
12. Sachs, J. J.: Am. J. Obst. & Gynec. **57**:965, 1949.

ENDOCARDIAL FIBROELASTOSIS OCCURRING IN THE ADULT

WILLIAM PANKE, M.D., AND ANTONIO ROTTINO, M.D.

NEW YORK, N. Y.

THE purpose of this paper is to present a report of an instance occurring in a young adult of endocardial fibroelastosis similar to that usually seen in infancy.

REVIEW OF LITERATURE

A thorough review of the literature disclosed only one case[1] similar to ours (reported by Fowler) indicating either that the disease is indeed rare or that it passes unrecognized. The clinical features of Fowler's case were a 20-year-old male with dyspnea on exertion for an indefinite period, dizzy spells for two months, and hemoptysis on the night of admission. On the third day of admission he died following a sudden acceleration of dyspnea. At autopsy the heart was found hypertrophied and dilated. The endocardium of all chambers was milky and opaque. The lungs, liver, kidney, and spleen were congested.

The author did not recognize the endocardial fibroelastosis as a congenital anomaly, but rather ascribed it to "some noxious agent which enters via the lungs." The ensuing fibrosis of the endocardium, he felt, caused an increase of peripheral resistance in the coronary circulation leading to secondary fibrosis of the myocardium.

Since the literature upon the subject of endocardial fibroelastosis is entirely concerned with the disease as seen in the infant, we shall review this literature only briefly.

We do this because the prime purpose of our communication is to suggest that this interesting endocardial lesion can persist into adulthood.

In 1818, Kreysig[2] first described hearts in infants characterized by predominance of endocardial thickening. For the next century, the majority of investigators ascribed the lesion to fetal inflammation and called it "fetal endocarditis." In 1918, Protoschnig[3] suggested that the lesion was noninflammatory in origin. It was not until 1941, when Gross[4] reviewed the subject and found that evidence for pre-existing inflammation was lacking, that authors began to agree that the lesion probably should be classified among the congenital malformations of the heart. Weinberg and Himmelfarb[5] in 1943 referred to the entity as "endocardial fibroelastosis," a term now generally accepted. During

From the Department of Pathology, St. Vincent's Hospital, New York, N. Y.
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the past ten years, many articles have appeared describing the pathologic features of fibroelastosis which include cardiac hypertrophy and dilatation; endocardial thickening, most commonly on the left side of the heart, with or without valvular involvement; and varying degrees of myocardial fibrosis. Cases previously reported as "idiopathic cardiac hypertrophy" in infants and children have in many instances been found also to fit this pathologic picture.

Recently, with more and more cases being reported, attempts to establish the clinical features have been made. Adam and Katz[6] were the first to analyze the clinical picture of endocardial fibroelastosis and have made this diagnosis in two living patients on the basis of their findings. Dennis and associates[7] classify 149 cases into fulminating, acute, and chronic types. They describe the clinical features of each, with criteria for differential diagnosis from other cardiopathies (coarctation of the aorta, anomolous left coronary artery, beriberi, rhabdomyoma of the myocardium, and glycogen-storage disease).

There still remains little known about the pathogenesis of this congenital anomoly. Also in speculation is the relation between the pathologic anatomy and the altered physiodynamics which lead to ultimate failure of the left ventricle.

Those concerned with the problem of fibroelastosis have proposed one possible pathogenesis. The seat of the alteration from normal embryologic development, according to Dennis and associates[7] (citing the work of Keith[8]), may be the bulbus cordis. This structure incorporates into the ventricles in early embryonic life and splits into a right and left part. The right bulbus forms part of the right ventricle and infundibulum, the left normally atrophies and disappears. The developing endothelial tissue of the bulbus, according to Keith, "behaves like granulation tissue in a granulating wound." It seems plausible that persistence and overgrowth of the endocardium of the left bulbus may result in a congenitally thickened endocardium of the left ventricle.

Hill and Reilly[9] feel that fibroelastosis is a collagen disease, but Adams and Katz[6] and others have validly refuted this theory.

The first explanation offered for the development of heart failure in cases of endocardial fibroelastosis was offered by Weinberg and Himmelfarb[5] based on the description of the coronary circulation by Wearn.[10] They state that the endocardial thickening interfered with blood flow through the arterioluminal, arteriosinusoidal, and Thebesian vessels, thereby rendering the myocardium ischemic.

Prior and Wyatt[11] feel that disturbance of function of papillary muscles resulting from degenerative changes is in part responsible for failure. They further add that the rigid endocardium probably interferes with ventricular diastolic filling and systolic expulsion. Angiocardiography done by Prec and Cassels[12] on an infant who at autopsy had endocardial fibroelastosis demonstrated no limitation of diastolic filling. However, prolonged outflow during systole was shown.

CASE REPORT

J. W., a 24-year-old married white nulligravida female was admitted to St. Vincent's Hospital on July 21, 1953, with a chief complaint of shortness-of-breath and hacking nonproductive cough of three days' duration.

Present Illness.—The patient had been working as a clerk when she began to be aware of episodes of vertigo, associated with generalized weakness, malaise, and dyspnea. On the second day of illness a nonproductive cough developed. She was seen by a physician who recorded her temperature as 103.4° F. and administered penicillin. There was slight improvement initially. On the morning of the following day, however, she became acutely dyspneic and was admitted to the hospital.

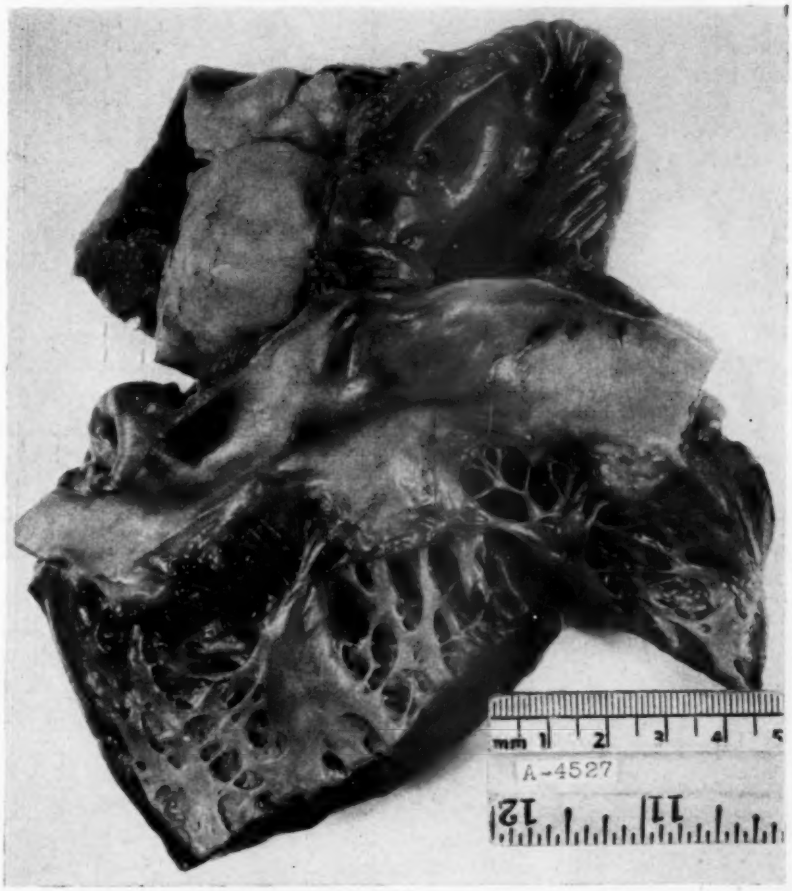

Fig. 1.—Left ventricle and auricle. Note the diffuse endocardial thickening extending from apex to the base.

Past History.—Since early childhood she had been under par. According to her family physician, the most prominent feature was hypochromic anemia. Hemoglobin varied between 48 per cent and 82 per cent; red blood count between 2,700,000 and 4,000,000; and color index between 0.7 and 0.8.

Five years prior to admission, she began to note repeated episodes of dyspnea and not infrequently blood-streaked sputum associated with colds, relieved by rest and antibiotics. At that time the electrocardiogram revealed a left bundle branch block. In a chest film nodular densities at the perihilar areas were observed and were interpreted as indicating the presence of Boeck's sarcoid. However, she was able to enjoy a moderately active life up to the time of this admission.

Physical Examination on Admission.—Temperature was 104.6; blood pressure, 120/80 mm. Hg; pulse rate, 136 per minute. The patient appeared to be acutely ill, tachypneic, dyspneic, and cyanotic. Examination of the ear, nose, and throat revealed pharyngeal inflammation.

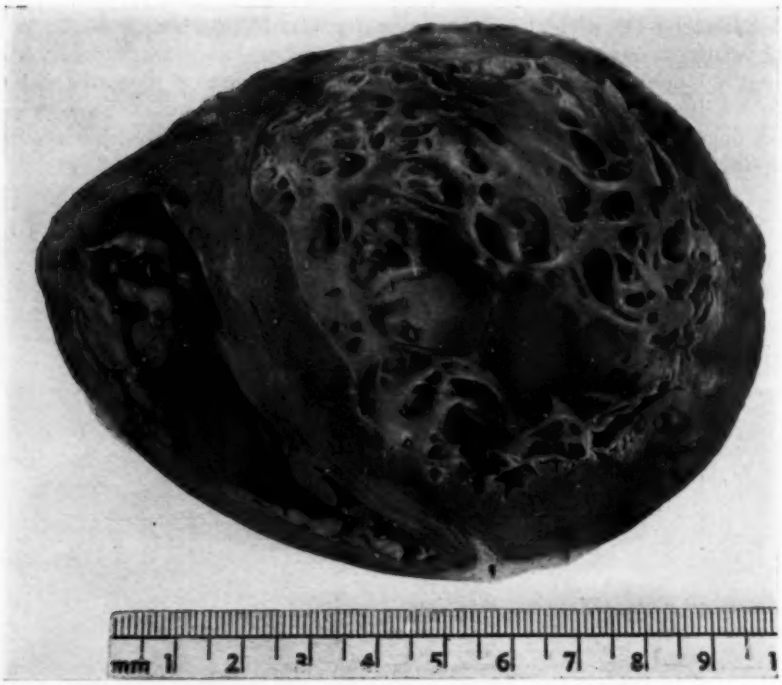

Fig. 2.—Cross section of the ventricle. Note that the endocardial thickening involves only the left ventricle, is diffuse, and extends about the entire circumference. Note involvement of Thebesian vessels and the thinning and fibrosis of the left ventricle musculature.

Fig. 3.—Hematoxylin and eosin stain; section through wall of left ventricle. The endocardial thickening is due chiefly to fibrosis and to a lesser extent to elastic tissue hyperplasia.

There were moist râles and expiratory wheezes throughout both lung fields. No alteration in the percussion note was detected. The cardiac rhythm was regular. Sounds were of good quality, but somewhat obscured by the breath sounds. No thrills, murmurs, or rubs were heard. The liver was palpable three fingerbreadths below the right costal margin and nontender. The spleen was not palpable. Cyanosis of the nailbeds was noted, but there was no peripheral edema.

Laboratory Data.—Urine specific gravity was 1.018 and two-plus albuminuria. No cellular elements were present. Examination of the blood disclosed a hemoglobin of 14.2 grams, a red cell count of 4,300,000, and a white cell count of 11,400 with 86 per cent neutrophils, 7 per cent lymphocytes, 6 per cent monocytes, and 1 per cent eosinophils. Fasting blood sugar was 120 mg. per 100 c.c. Blood urea nitrogen was 124 mg. per cent, creatinine 6 mg. per cent. Blood Kahn was negative. The blood albumin-globulin ratio was 3.9/2.3. Sedimentation rate was 3 mm. in 1 hour. A blood culture on admission showed no growth. X-rays of the hands and long bones were normal. X-ray of the chest revealed an extensive infiltration in both lungs. There were also noted several nodular densities at the perihilar areas. The heart was enlarged, especially in its left ventricular component with a straightening of the left border. An electrocardiogram demonstrated left bundle branch block and multiple ventricular extrasystoles.

Course in the Hospital.—Initial therapy consisted of oxygen by mask, Cedilanid, aminophylline, Demerol and penicillin. Response was satisfactory and on the morning of the second hospital day, she was afebrile and breathing comfortably. However, on that day she had three episodes of emesis of ingested food and mucus. Urinary output during her illness was adequate.

On the third day of hospitalization she became very dyspneic, developed pulmonary edema, went into shock, and died.

Autopsy Findings.—The body was that of a well-developed and well-nourished young adult white female with cyanosis of the face, neck, and lips. There were 350 c.c. of clear transudate in each pleural space. The pericardium appeared normal; there was no pericardial effusion.

The heart weighed 400 grams. It was globular in shape and flabby in consistency. The epicardium was normal. All chambers were dilated. The endocardium of the left ventricle was diffusely thickened, white and opaque (Fig. 1). Similar endocardial thickening was noted in the left atrium. The endocardium over the papillary muscles of the right ventricle was also thickened.

The myocardium of the left ventricle was 14 mm. thick at the base. The posterior wall was fibrotic and thin, measuring 4 mm. in thickness (Fig. 2). In addition, there were numerous fibrotic areas in the anterior and septal walls. No mural or appendage thrombi were present. The valves were normal. The coronary arteries were thin, flexible and patent.

The right lung weighed 1,100 grams; the left, 740 grams. The surfaces were smooth and the lungs felt boggy. On section, the cut surface bulged, was rust colored and very edematous. The trachea and bronchial tree were filled with rusty, frothy fluid.

The liver weighed 1,820 grams. The surface was smooth, the edge round. On section, it had a striking nutmeg appearance.

Microscopic: Lungs: The interalveolar septa were thickened and the lining cells swollen. The acini were packed with large numbers of swollen macrophages engored with hemosiderin. This was noted in all lobes.

Liver: Central necrosis involving about 60 per cent of each liver lobule was present.

Heart: The endocardial thickening so pronounced grossly was found to be due to varying degrees of fibrosis and elastic tissue hyperplasia with predominance of the former (Fig. 3). In several sections the endocardial thickening was such as to cause marked narrowing of the mouths of the Thebesian vessels. The thickening of the intima of these vessels extended for some distance into the myocardium. The myocardium, particularly that of the inner half of the posterior wall of the left ventricle, contained foci of degenerating muscle fibers and irregular areas of fibrous tissue replacement. There were present in some of these foci small numbers of lymphocytes.

Anatomical Diagnosis: Endocardial fibroelastosis. Chronic passive congestion of lungs. Chronic passive congestion of liver.

DISCUSSION

The case we report was the first recognized by us in a total of 3,500 autopsies on adults. Review of all these autopsied cases disclosed several which probably were examples of fibroelastosis also, but inasmuch as the hearts were no longer available for intensive histopathologic study, they were not included in this report. The fact that we recognized our present case as an instance of fibroelastosis at all was due to the fact that we had recently observed the same condition in three infants who came to autopsy.

From a review of the literature it is evident that fibroelastosis is in general incompatible with life. Thus in a collected series of 126 cases,[1,4,7,9,11-32] 59 per cent died within the first 6 months of life and 78 per cent by one year. There is one reported instance of a child dying at 11½ years.[13] Fowler's[1] patient was 20 years of age, while ours was 24 years at the time of death, hence, the uniqueness of our case report.

The extensiveness of the myocardial degeneration and fibrosis is of interest. Lack of coronary disease would implicate the Thebesian circulation as the chief contributor to hypoxia of the heart. Anatomic evidence for this was observed in the narrowed mouths of the Thebesian vessels and of their lumina along their course in the myocardium. Acceptance of the role of the Thebesian vessels as prime contributor to the myocardial fibrosis in this case would emphasize the importance of this system to the myocardial circulation.

SUMMARY

A brief review of the concept of fibroelastosis is presented and a case in a young adult is reported similar to that seen in infants.

This case probably represents an extremely rare case of a patient with this disease maintaining sufficient cardiac reserve to carry her into adult life.

REFERENCES

1. Fowler, M.: Clinico-pathological Study of 2 Cases of Idiopathic Cardiac Hypertrophy With Congestive Failure, M. J. Australia **1**:672, 1947.
2. Krstulovic, E.: Idiopathic Hypertrophy of the Heart, Monatsschr. Kinderh. **33**:113, 1926.
3. Potoschnig, G.: Ueber die Kongenitale diffuse Endokardhyperplasie des linken Ventrikels, Ztschr. Anat. **4**:234, 1918.
4. Gross, P.: The Concept of Fetal Endocarditis, Arch. Path. **31**:163, 1941.
5. Weinberg, T., and Himmelfarb, A. J.: Endocardial Fibroelastosis, Bull. Johns Hopkins Hosp. **72**:299, 1943.
6. Adams, F. H., and Katz, B. L.: Endocardial Fibroelastosis, J. Pediat. **41**:141, 1952.
7. Dennis, J. L., Hansen, A. E., and Corpening, T. N.: Endocardial Fibroelastosis, Pediatrics **12**:130, 1953.
8. Keith, A.: The Fate of the Bulbus Cordis in the Human Heart, Lancet **2**:1267, 1924.
9. Hill, W. T., and Reilly, W. A.: Endocardial Fibroelastosis, Am. J. Dis. Child. **82**:579, 1951.
10. Wearn, J. T.: Observations on the Morphology and Functions of Some of the Components of the Coronary Circuit, Bull. Johns Hopkins Hosp. **68**:353, 1941.
11. Prior, J. T., and Wyatt, T. C.: Endocardial Fibroelastosis, Am. J. Path. **26**:969, 1950.
12. Prec, K. J., and Cassels, D. E.: Functional Aspects of Congenital Defects Affecting the Left Ventricle, J. Pediat. **41**:451, 1952.
13. Blumberg, R. W., and Lyon, R. A.: Endocardial Sclerosis, Am. J. Dis. Child. **84**:291, 1952.
14. Benjamin, B., and Simon, M.: So-called Congenital Idiopathic Hypertrophy of Heart, Am. J. Dis. Child. **59**:842, 1940.

15. Collier, F., and Rosahn, P.: Endocardial Fibroelastosis, Pediatrics **7**:175, 1951.
16. Cosgrove, G. E., Jr., and Kaump, D. G.: Endocardial Sclerosis in Infants and Children, Am. J. Clin. Path. **16**:322, 1946.
17. Edmonds, H. W., and Seelye, W. B.: Endocardial Sclerosis, Pediatrics **7**:651, 1951.
18. Kenny, F. E., and Sanes, S.: Dilatation and Hypertrophy of Heart in Infancy, J. Pediat. **3**:321, 1933.
19. Kugel, M. A.: Enlargement of the Heart in Infants and Young Children, AM. HEART J. **17**:602, 1939.
20. Leary, D. C., Welt, L. G., and Beckett, R. S.: Infectious Mononucleosis Complicating Pregnancy With Fatal Congenital Anomaly of Infants, Am. J. Obst. & Gynec. **57**:381 1949.
21. Lewis, K. C.: Cardiac Enlargement of Unknown Etiology in Infants and Children, J. Pediat. **39**:698, 1951.
22. Lippincott, S.: Congenital Atresia of Aortic Valve Without Septal Defect, AM. HEART J. **17**:502, 1939.
23. MacGregor, R. R., and McKendry, R.: Fetal Endocarditis, Canad. M. A. J. **50**:433, 1944.
24. Mahon, G. S.: Idiopathic Hypertrophy of the Heart With Endocardial Fibrosis, AM. HEART J. **12**:608, 1936.
25. Neely, J. M.: Idiopathic Cardiac Enlargement Occurring in Infants and Children, Ann. Int. Med. **15**:727, 1941.
26. Powers, G. F., and Le Compte, P. M.: Remarks on Case of Congenital Idiopathic Hypertrophy of the Heart, J. Pediat. **13**:760, 1939.
27. Sano, M. E., and Anderson, N. A.: Elastic Tissue Hyperplasia of the Endocardium, Arch. Path. **33**:533, 1942.
28. Schefrin, A. E.: Myocardial Fibrosis in Infancy, J. Pediat. **36**:360, 1950.
29. Sprague, H. B., Bland, E. F., and White, P. D.: Congenital Idiopathic Hypertrophy of the Heart, Am. J. Dis. Child. **41**:877, 1931.
30. Cabot, R. C.: Case Reports of the Massachusetts General Hospital, No. 34361, New England J. Med. **239**:373, 1948.
31. Stadler, H. E., Reid, C. A., and Friedman, H. P.: Prenatal Fibroelastosis, J. Pediat. **36**:370, 1950.
32. Weisman, S. F.: Congenital Idiopathic Hypertrophy, Arch. Path. **33**:365, 1942.

UNUSUAL BIGEMINAL VENTRICULAR RHYTHM

RALPH MILLER, M.D., AND NICHOLAS A. ANTONIUS, M.D.

NEWARK, N. J.

BIGEMINY is one of the relatively common disturbances of rhythm which is recorded electrocardiographically. The possible combinations of beats of various origins which may constitute a bigeminal rhythm are numerous and several comprehensive classifications of bigeminy have appeared in the literature.[1-4] The purpose of this communication is to describe an unusual type of bigeminy, previously unclassified, due to two ventricular foci alternately producing sequences of an extrasystolic and automatic beat.

CASE HISTORY

The patient was a 64-year-old white man who was first seen on Feb. 21, 1952, with a chief complaint of shortness-of-breath. He had had exertional dyspnea and substernal pain for the past three years and also had noted intermittent edema of the legs. He was taking digitoxin 0.2 mg. daily. The diagnosis was arteriosclerotic heart disease, enlarged heart, coronary artery sclerosis, cardiac insufficiency, anginal syndrome, auricular fibrillation, ventricular extrasystoles, pulsus bigeminus. Because of the electrocardiographic findings, a diagnosis of digitalis intoxication was made, and the drug was discontinued temporarily. Later digitalis therapy with use of the powdered leaf was resumed, and intoxication has not recurred.

Analysis of the electrocardiograms: Auricular fibrillation was present in all tracings and the QRS complexes of supraventricular origin showed the pattern of left bundle branch block. The arrhythmia recorded on the first two occasions is selected for detailed analysis.

Fig. 1 consists of selected strips from a long Lead II obtained on Feb. 21, 1952. The QRS complexes of supraventricular origin are of the RS type, with slurring of the upward limbs of both the R and S deflections, and with a QRS interval of 0.12 second. In Fig. 1, *A* a constant bigeminal ventricular rhythm is present. Each ventricular beat of the dominant rhythm is coupled with a ventricular extrasystole. The second, fourth, sixth, eighth, twelfth, fourteenth, and sixteenth QRS complexes are ventricular extrasystoles, all from the same focus. They are of the rS type, and the QRS interval measures 0.14 second. The tenth QRS complex is an extrasystole originating in a second focus; it is of the RS type, and the QRS interval measures 0.12 second. It resembles the normal QRS in contour and may have its origin in the bundle of His. The interval between the first pair of ventricular beats is 0.54 second, between the second pair 0.52, and following this all ventricular extrasystoles are coupled to the preceding b ts at a fixed interval of 0.48 second.

In Fig. 1, *B* the first four ventricular beats are supraventricular in origin. They are quite regularly spaced and this may indicate the presence of atrioventricular block with the pacemaker controlling the ventricles in the atrioventricular node or common bundle below the site of block.

From the Department of Cardiology, St. Michael's Hospital, Newark, N. J.

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The fifth beat is premature. It is of the Rs type, with marked notchings of the R wave. The QRS interval is 0.12 second, the S-T segment is depressed, and the T wave diphasic. Throughout this paper ventricular complexes conforming to this contour will be designated the F1 type, indicating a common origin in a single ventricular focus. The sixth and seventh ventricular complexes are automatic beats. Their contour is of the rS type, and the QRS interval is 0.12 second. The S-T segments are slightly elevated, and the T waves are upright. Complexes of this contour will be referred to as the F2 type. The extrasystole, beat number eight, arises from a focus different from all others in this tracing. Ventricular complex number nine is an automatic beat, probably from the same focus as the extrasystole, beat number five, and therefore is an F1 type of beat. Slight differences in contour between complexes five and nine may be due to variations in the preceding diastolic interval. The last two complexes in strip *B* are of supraventricular origin.

In Fig. 1, *C* the first and third beats are of supraventricular origin and are coupled with ventricular extrasystoles at intervals of 0.48 and 0.49 second, respectively. Starting with the fifth ventricular beat complete atrioventricular block occurs, with the ventricular rhythm controlled by impulses originating in Focus 1. The dominant idioventricular rhythm is paired with ventricular extrasystoles occurring after a coupling interval of 0.50 to 0.56 second. These extrasystoles are very similar to, and probably originate in, the same focus as automatic beats of the F2 type seen in Fig. 1, *B*. The R-R interval between the dominant idioventricular beats ranges from 1.66 to 1.72 seconds in duration.

To summarize the findings in Fig. 1, auricular fibrillation is present, with the following ventricular mechanisms: Ventricular beats of supraventricular origin, multifocal ventricular extrasystoles, automatic beats from two different foci, extrasystoles originating in the same foci as the automatic beats, short periods of atrioventricular block with the ventricular pacemaker in the atrioventricular node, idioventricular rhythm, and bigeminal rhythm due to pairing of extrasystoles with ventricular beats of supraventricular and idioventricular origin.

In Fig. 2, *A* the first and fifth beats are of supraventricular origin, the third beat is an automatic impulse of the F2 type, and the second, fourth, and sixth beats are extrasystoles of multifocal origin. An interesting and complex bigeminal rhythm begins with beat number seven. This is an automatic beat of the F1 type. It is followed by an extrasystole of the F2 type. Then an automatic beat originates from the same focus as the preceding extrasystole. This F2 type automatic beat is in turn followed by an extrasystole of the F1 type. The next beat, number eleven, is an automatic beat from Focus 1 and then the entire sequence is repeated. The sequences, automatic beat F1 type, extrasystole F2 type, automatic beat F2 type, extrasystole F1 type recur also in Fig. 2, *B* starting with the fifth complex. Thus these sequences of beats of different origins set up an unusual type of bigeminy. It will be seen that during this arrhythmia four different intervals are present. These, with their corresponding times, may be listed as follows.

1. Automatic beat F1, extrasystole F2—0.52 second
2. Extrasystole F2, automatic beat F2—1.24 to 1.28 seconds
3. Automatic beat F2, extrasystole F1—0.48 to 0.52 second
4. Extrasystole F1, automatic beat F1—1.36 to 1.40 seconds

Since the above intervals are almost constant during the runs of bigeminy, complete atrioventricular dissociation may be considered to be present.

Thus, in Fig. 2, multifocal ventricular extrasystoles are present coupled with beats of supraventricular origin. Also, intermittent periods of complete atrioventricular block occur during which the ventricles are dominated by impulses originating in two different foci, which produce in sequence and alternately, automatic beats and extrasystoles with a resulting bigeminal rhythm

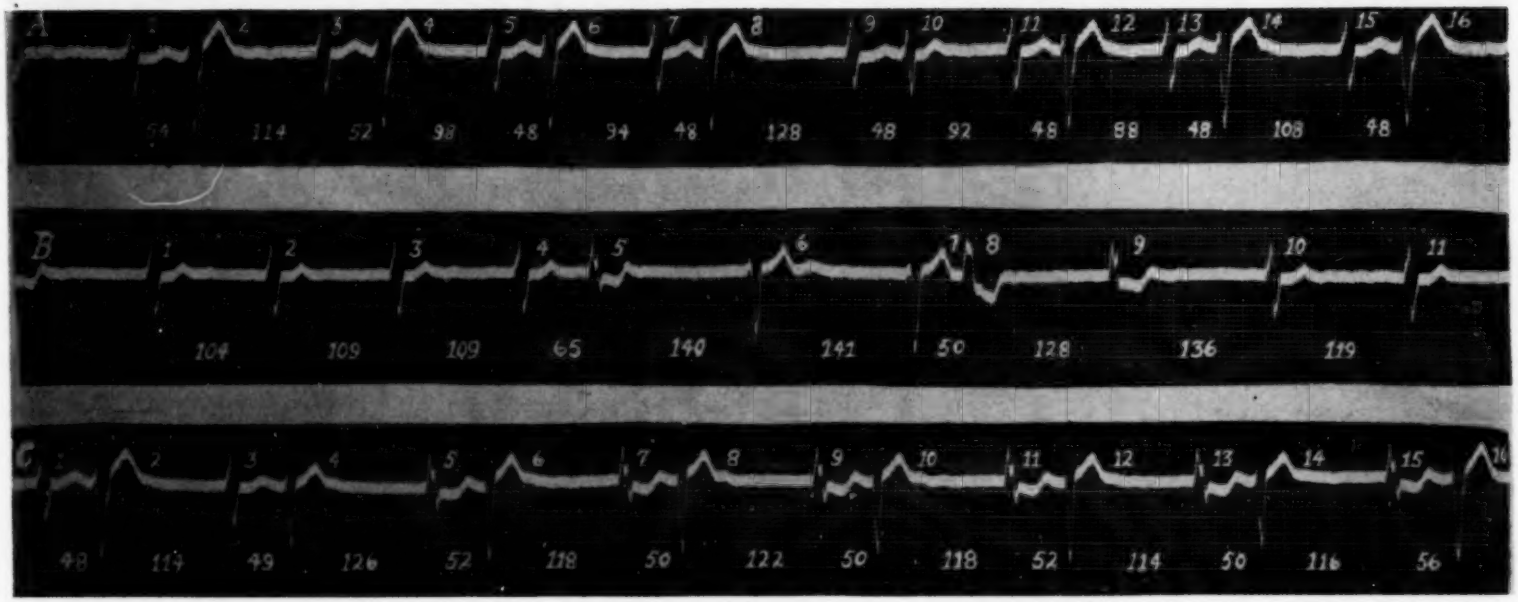

Fig. 1.—Selected strips of Lead II taken on Feb. 2, 1952. Upper row of numbers refers to QRS complexes. Lower row of numbers represents R-R intervals in hundredths of a second.

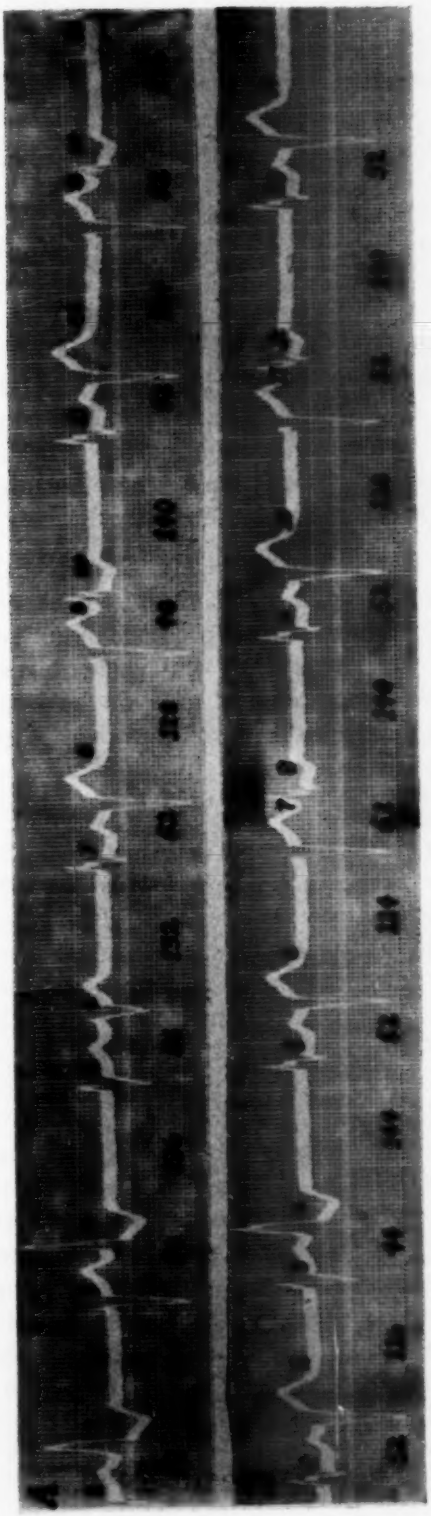

Fig. 2.—Selected strips Lead II obtained on Feb. 4, 1952.

COMMENT

It will be noted that despite the presence of auricular fibrillation the dominant ventricular rhythm is fairly regular, and the extrasystoles are followed by pseudo-compensatory pauses. This tendency towards regularity in auricular fibrillation with ventricular bigeminy has been noted previously.[1] Two explanations for this phenomenon are possible. The ventricular rhythm tends to be slow and regular because of the presence of a high degree of atrioventricular block. This possibility is suggested by the tracing in Fig. 1, *B*, where the intervals R_1-R_2, R_2-R_3, R_3-R_4 and R_{10}-R_{11} are almost the same in duration. The second possibility is that the ventricular extrasystolic impulses are conducted back to the atrioventricular node, and although not entering the auricles, nevertheless set up a refractory period in the atrioventricular node and subsequent orthograde conduction is impeded. When conduction is progressively more markedly depressed automatic beats occur, and finally complete atrioventricular block with the idioventricular focus in one of the bundle branches may result.

The most interesting feature of this case is the unusual bigeminal rhythm illustrated in Fig. 2. Two ventricular foci giving rise in sequence and alternately to extrasystoles and automatic beats in the presence of auricular fibrillation with complete atrioventricular block cause a ventricular bigeminy. It has long been known that extrasystolic impulses tend to favor the occurrence of automatic beats from the same focus,[5] and also it is well known that extrasystoles may be triggered off by preceding beats of any origin. For an excellent review of the pertinent literature the reader is referred to Scherf and Schott's monograph.[6]

Apparently what happens in this case, in sequence, is as follows: An automatic beat occurs from an origin in Focus 1. This beat after a fixed interval sets off an extrasystole originating in Focus 2. The extrasystole favors the production of an automatic beat from the same focus (Focus 2) and also it discharges Focus 1, inhibiting automatic impulse formation at the latter site. Therefore the third beat is an automatic beat from Focus 2. This beat in turn triggers off an extraystole from Focus 1. The latter extrasystole now predisposes to formation of an automatic beat in Focus 1, and at the same time discharges Focus 2 before it can produce a second automatic beat, and inhibits it. Therefore the next beat is an automatic beat originating in Focus 1. This sequence is repeated and thus gives rise to a sustained bigeminal rhythm. The R-R interval preceding automatic beats from Focus 1 is fixed between 1.36 and 1.40 seconds and for Focus 2 at 1.24 to 1.28 seconds. The difference in time between the two automatic intervals is sufficiently small to accommodate the above mechanism if one takes into consideration the time for the extrasystolic impulse from one focus to reach the opposite focus and for its inhibitory effect upon subsequent impulse formation in the latter area. Therefore the focus with the fastest inherent rate would not necessarily take command of the heart and a sort of interference dissociation between the two ventricular foci results.

SUMMARY

1. An unusual type of ventricular bigeminy is reported.

2. In the presence of auricular fibrillation with complete atrioventricular block the ventricular rhythm was controlled by two ventricular foci acting in sequence and alternately as extrasystolic and automatic foci.

3. The possible mechanism of this arrhythmia is discussed.

REFERENCES

1. Benaros, M.: Bigeminismo, Prensa méd. argent. **20**:581, 1933.
2. Stewart, H. J.: Cecil's Textbook of Medicine, Philadelphia, 1944, W. B. Saunders Company.
3. Parsonnet, A. E., Miller, R., Bernstein, A., and Klosk, E.: Bigeminy, Am. Heart J. **31**:74, 1946.
4. Miller, R., and Perelman, J. S.: Atrionodal Rhythm With Ventricular Bigeminy, Am. Heart J. **33**:34, 1947.
5. Lewis, T.: Observations Upon Disorders of the Heart's Action, Heart **3**:279, 1912.
6. Scherf, D., and Schott, A.: Extrasystoles and Allied Arrhythmias, New York, 1953, Grune and Stratton, Inc.

UNUSUAL COMBINATION OF CARDIAC ANOMALIES IN A CASE OF ISOLATED DEXTROCARDIA

GERARDO B. POLANCO, M.D., AND ALBERT M. POWELL, M.D.

BALTIMORE, MD.

THAT the heart can present itself with its major portion lying to the right of the midline has been recognized for centuries. During this time the appertaining literature has become extensive in spite of the rarity of this condition.

Variability and inconsistency prevail in the terminology applied to these cases. In this communication, the term dextrocardia is used simply to refer to cases in which the orientation of the heart to the right is due to developmental factors intrinsic to the heart, and not to those in which it is the result of mechanical displacement due to congenital or acquired anomalies of the surrounding structures. Terms such as dextroversio cordis, dextropositio cordis, transpositio cordis and "true", "pure," "ideal," complicated and uncomplicated dextrocardia are avoided. The terms "left" and "right" are applied to the heart chambers to designate the position of the equivalent chambers in the normally developed heart.

Dextrocardia is a part of total situs inversus, in which the position of all the viscera is inverted from right to left, and the anteroposterior relationship is preserved. This is frequently referred to as a "mirror image" type of inversion.

Situs inversus may be partial. The heart may be inverted with only a few of the other viscera. Rarely, the whole organ complex is inverted with the exception of the heart. This is the case in situs inversus with levocardia. Not infrequently the heart is the only organ inverted. This is called isolated dextrocardia.

In cases of total situs inversus, the heart is likely to be normal in all respects other than its inversion. In the other instances, disabling cardiac anomalies are likely to occur.[1]

In the majority of cases of isolated dextrocardia, the "mirror image" type of cardial configuration is lacking. The chambers preserve their normal right-to-left relationship, but their anteroposterior relationship is inverted.[2] This type of inversion has been properly termed "pivotal" because it can be visualized by assuming that the heart has rotated around the vertebral axis in a clockwise manner. The aorta, instead of arising posterior to the pulmonary artery, arises anteriorly and slightly to its right. A smaller number of cases of isolated dextrocardia show the same type of "mirror image" orientation that is seen in cases of total situs inversus, but the aorta arises anterior to the pulmonary artery.

From the Department of Pathology, University of Maryland School of Medicine, Baltimore, Md., and the Department of Pediatrics, University Hospital, Baltimore, Md.

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Great difficulties may be encountered in identifying the heart chambers in isolated dextrocardia, as such bizarre anomalies may accompany this condition that the normal landmarks are frequently lost or confused. For this reason it has not been possible to set clear-cut criteria that will in all cases provide easy identification of the "right" and "left" chambers. This difficulty originates partly in the fact that the heart need not be inverted as a whole. The great veins, the auricles, the valves, the ventricles, and the arterial trunks may be inverted individually or in various combinations. In addition, the number of cusps or leaflets in a valve may be altered. Entire valves or chambers may be absent; valves may be fused; and embryonic blood vessels may persist. When the venous pattern reproduces or closely simulates the normal design, or a mirror image thereof, the pulmonary veins provide reliable criteria for identification of the "left" auricle. Likewise, identification of the ostia of the coronary sinus and venae cavae is frequently helpful in identifying the "right" auricle. Of these, the relationship of the coronary sinus to the right auricle is the most constant. Much less consistent than the attachments of the veins to the auricles are the attachments of the aorta and pulmonary artery to the ventricles. If the same side of the heart that receives blood from the lungs gives rise to the pulmonary artery, there is true transposition of the arterial trunks. Transposition may be present, but "corrected," if in addition to the inversion of the arterial trunks, the auriculoventricular attachments have also been interchanged.[3] In this case the "right" ventricle is attached to the "left" auricle and to the aorta. Therefore, it becomes evident that final identification of the chambers should always be based on detection of the more constant anatomic peculiarities of each. Recently Lev has presented a useful summary of these features.[4] The auricles may be identified by inspection of the interauricular septum, the "right" surface being that which presents the limbus and the fossa ovalis. The "left" surface may present the valve of the foramen ovale (septum primum) or its adherent remnant. The "right" ventricle should always have a conus. Its septal surface contains papillary muscles. If the right ventricle is rudimentary, it usually resembles the normal conus arteriosus. Absence of a conus and absence of papillary muscles in the septal surface are important characteristics of the "left" ventricle. The number of leaflets in the auriculoventricular valves need not follow the normal correlation with the side of the ventricle which they guard. This is especially true when only one valve has developed.

As an example of isolated dextrocardia with an unprecedented combination of cardiac anomalies. the following case is presented.

CASE REPORT

The patient, a 9-day-old white boy, was admitted from another hospital on May 19, 1953, because of jaundice and rapid respiration which had been present since May 13. There was questionable evidence of cyanosis.

The mother, age 30, was of blood group A_1MNRh_1hr' positive. This, her second pregnancy, was complicated by hyperemesis. She also had "a very bad cold" during the fourth month of pregnancy. The labor, of 45 minutes' duration, ended in a spontaneous vaginal delivery. The infant weighed seven pounds and twelve ounces. No resuscitation was necessary. There is one sister, age 3½ years, who is living and well. The paternal grandmother has diabetes mellitus. A maternal uncle had convulsions of unknown etiology as a baby but is a normal adult at present.

Physical Examination.—Temperature, 99.2°F.; respiration, 72; pulse, 180. The patient was a well developed, well nourished infant with mild icterus. There were no skin rashes. He was normally active and alert for his age. Crying produced questionable cyanosis. The anterior fontanelle was full, but not tense. The bony thorax was normal. Examination of the lungs revealed a few fine inspiratory râles in the right upper lobe posteriorly. The precordial pulsation was felt along the left sternal border and also at the lower right sternal border. The heart extended to both the right and left mid-clavicular lines. The heart sounds were rapid and regular. They were heard equally to the right and left of the sternum. A Grade 2, rather rough systolic murmur was heard best between the left nipple and the sternum. This murmur radiated to the right and also upwards along the left sternal border. The abdomen was soft. The liver and spleen were palpated 3 cm. and 2½ cm., respectively, below the costal margins. Both femoral artery pulsations were palpable.

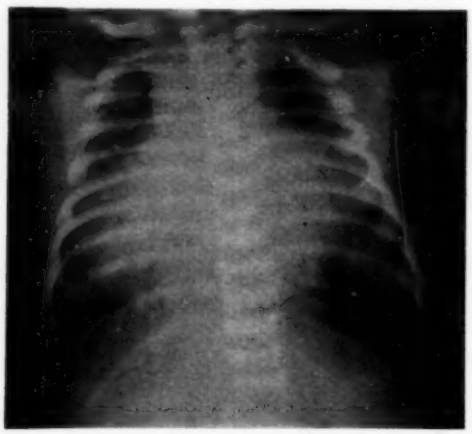

Fig. 1—Roentgenogram of chest, taken on seventh hospital day.

Laboratory Studies.—Hemoglobin, 14.5 grams; blood urea nitrogen, 22 mg. per cent; blood sugar, 72 mg. per cent; STS, negative; blood group, OM RH_1hr' negative. Further blood antibody studies on the mother and baby did not produce evidence of erythroblastosis fetalis. An electrocardiogram on May 20 revealed "right ventricular preponderance" which was interpreted as being within normal limits for the child's age. A repeat electrocardiogram suggested dextrocardia. A chest x-ray on May 20 (Fig. 1) was interpreted as indicative of congential heart disease with dextrocardia. Engorgement of the pulmonary vessels was noted. The abdominal viscera were in normal relationship. A roentgenogram of the chest taken on May 22, 1953, was interpreted as indicative of dextrocardia and an associated interatrial septal defect.

Course in Hospital.—On May 20 the infant was digitalized with a dose of 0.033 mg. of Crystodigin per kilogram of body weight. One-tenth of this amount was used daily for maintenance. Immediate response was moderately good, but an additional dose of Crystodigin had to be administered on the fifth day of therapy. On the eighth day the daily dose of Crystodigin was doubled. However, the child continued to do poorly and on the tenth hospital day became deeply cyanotic and developed fine inspiratory râles throughout both lung fields. The liver then was palpable 4 cm. below the costal margin. Despite oxygen and digitalis therapy, the child got progressively worse and expired on the eleventh hospital day.

At the *post-mortem examination*, the heart showed marked enlargement, weighing 50 grams instead of the normal 20 grams. The apex pointed to the right. All the remaining viscera were found in their normal locations. The ascending aorta lay anterior to a widened pulmonary artery. Immediately distal to the exit of the innominate artery there was marked narrowing of the aorta. This continued to, but not through, the point of origin of the subclavian artery. After the coarctation, the aorta joined a widely patent ductus arteriosus and continued as a vessel of normal caliber. The aortic arch was oriented to the left and descended on the left of the vertebral bodies.

The pulmonary artery bifurcated normally beneath the aortic arch. Both coronary arteries arose from the base of the aorta. The aortic valve had three cusps which were fused. The aorta arose from a rudimentary ventricle which had no communication with the auricles, and which, by virtue of its shape and position, was reminiscent of the normal conus arteriosus. This chamber was located along the base of the ventricular portion of the heart. It was oriented to the right and its tip lay posteriorly. A very small high interventricular septal defect communicated this rudimentary ventricle with the other ventricle, which was large and hypertrophied. On the left surface of the "septum," the small defect was hidden by the septum membranaceum. The auricles were continuous with each other through a large septal defect which, from a functional standpoint, converted them into a single chamber. The underdeveloped valve of the foramen ovale had its attachments on the left surface of the septum. The "left" auricle was dilated, and it lay posteriorly and to the left of the "right" auricle. Each auricle bore an auricular appendage.

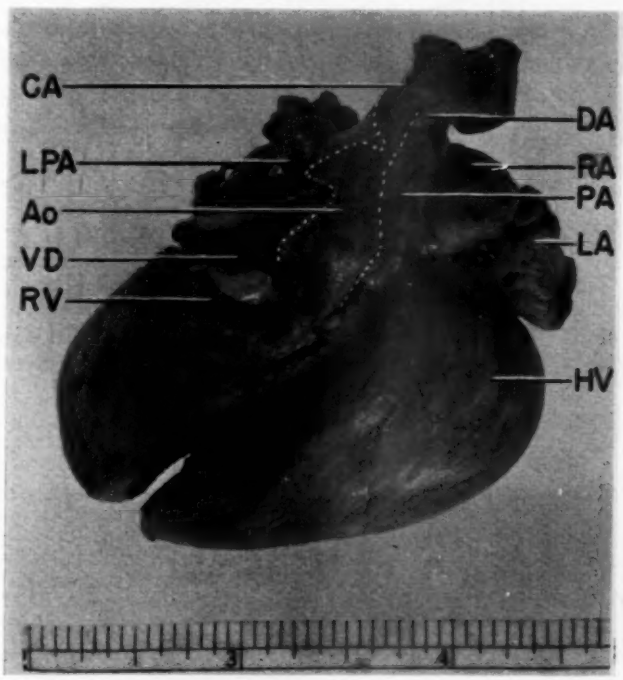

Fig. 2—Anterior view of the heart. The dotted lines mark the borders of the aorta. *CA*, Distal limit of the coarctation; *LPA*, Left pulmonary artery; *Ao*, Aorta, *VD*, Interventricular septal defect; *RV*, rudimentary ventricle; *DA*, Ductus arteriosus; *RA*, Right auricular appendage; *PA*, Pulmonary artery; *LA*, Left auricular appendage; *HV*, Hypertrophied ventricle.

The arterial trunks were located to the right of the right auricular appendage rather than between the two. The right auricle received the superior and inferior venae cavae and the coronary sinus, and it had no communication with the ventricles. The anterior wall of the right auricle was apposed to the posterior wall of the pulmonary artery (Fig. 2). It could be easily dissected away from the artery exposing a circular, muscle-free membrane, which apparently represented the displaced floor of the auricle; that is, the undeveloped auriculoventricular valve. The left auricle received the pulmonary veins and drained into the large ventricle by means of a normal appearing valve which had three leaflets. The large ventricle gave rise to the pulmonary artery, and the pulmonic valve was normal. A conus arteriosus was not present on this ventricle. The leaflets of the atrioventricular valve showed no attachment to the "septal" surface of the ventricle, and this surface did not contain papillary muscles. The anterior leaflet of this valve bore the same relationship to the pulmonic valve that the anterior mitral leaflet bears to the aortic valve in the normal heart.

The *anatomic diagnosis* was dextrocardia without inversion of the auricles; tricuspid atresia; rudimentary right ventricle; transposition of the arterial trunks; fused aortic valve; patent foramen ovale; hypertrophy of left ventricle; coarctation of the aorta; patent ductus arteriosus; interventricular septal defect; tricuspid auriculoventricular valve.

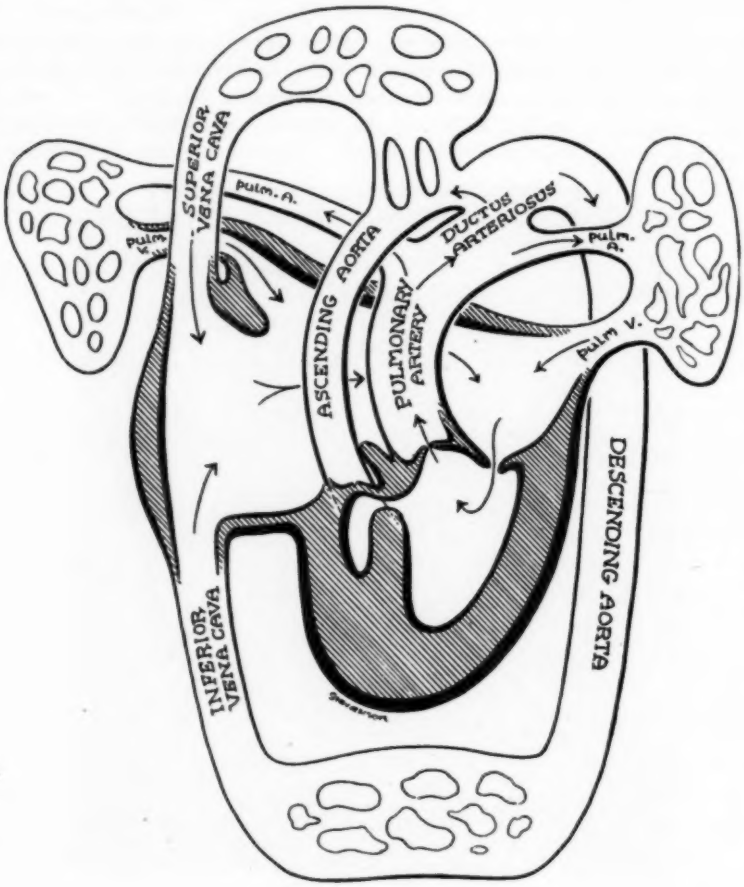

Fig. 3.—Diagrammatic representation of the course of the circulation in the heart.

The pathway of the blood was visualized as follows (Fig. 3). The systemic blood entered the right auricle from the venae cavae and mixed freely with the blood that entered the left auricle from the pulmonary veins. From here it was drained into the left ventricle from which it entered the transposed pulmonary artery, part of it going to the lungs and the remainder reaching the aorta through the ductus arteriosus. Part of the blood entering the aorta flowed back through the coarctation, thus reaching the left subclavian, left internal carotid, innominate and coronary arteries. No significant amounts of blood could have reached the aorta through the small interventricular septal defect and the fused aortic valve. The development of the head was normal.

COMMENTS

The combination of tricuspid atresia, hypoplasia of the right ventricle, and pulmonary atresia it is not uncommon in congenital heart disease.[5] This case shows the same basic combination, but the atretic vessel is the transposed aorta.

As the "right" ventricle is clearly located on the right side of the heart, this cannot be interpreted as a "mirror image" type of ventricular inversion. Therefore, the inversion of the ventricles is of the pivotal type. It must be assumed that if the hypoplastic ventricle would have developed to normal size, its major portion would have appeared in a posterior position. This assumption would be equally necessary if the hypoplastic chamber were interpreted as "left" ventricle, thus converting the ventricular relationship to the "mirror image" type. The latter interpretation is anatomically untenable in this case.

Of equal interest is the fact that in this case of dextrocardia the auricles show the relationship of levocardia. Neither the right-to-left nor the antero-posterior auricular relationships are altered. Therefore, the case does not fit into any of the categories recently offered by Lev in his appealing classification of positional variations of cardiac chambers.[4]

The narrowing of the aorta is unusual also in that it involves the segment between the innominate and the left subclavian arteries.

The authors are indebted to Dr. H. B. Taussig of the Johns Hopkins Hospital of Baltimore, Md., and to Dr. D. L. Reimann and Dr. S. Scherlis of the University Hospital of Baltimore for the valuable assistance received in various aspects of the study and report of this case.

REFERENCES

1. Lichtman, S. S.: Isolated Congenital Dextrocardia, Arch. Int. Med. **48**:683, 1931.
2. Reinberg, S. A., and Mandelstam, M. E.: On the Various Types of Dextrocardia and Their Diagnostics, Radiology **11**:240, 1928.
3. Gould, S. E.: Pathology of the Heart, Springfield, Ill., 1953, Charles C Thomas.
4. Lev, M.: Pathologic Diagnosis of Positional Variations in Cardiac Chambers in Congenital Heart Disease, Lab. Invest. **3**:71, 1954.
5. Taussig, H. B.: Congenital Malformations of the Heart, New York, 1947, Commonwealth Fund.

PURULENT PERICARDITIS AND EMPYEMA CAUSED BY HEMOPHILUS INFLUENZAE, TYPE B

ROLF LUNDSTRÖM, M.D.

STOCKHOLM, SWEDEN

PURULENT pericarditis is an infrequent complication of infections in childhood. When it does occur, it is usually in association with infectious processes in the lungs and pleurae. In some cases it may be due to infection following penetrating wounds of the pericardium. As might be expected, the incidence of purulent pericarditis has decreased since the introduction of antibiotics (Griffith and Wallace[1]). It nevertheless still occurs and is then not uncommonly caused by organisms resistant to one or several antibiotics. Cases have been reported in which pneumococci, staphylococci, or streptococci were responsible, whereas *B. tularense*, *Klebsiella pneumoniae*, *Hemophilus pertussis*, and *Hemophilus influenzae* have less often been implicated. Untreated purulent pericarditis is almost invariably fatal. Reeves[2] found that pericarditis had been diagnosed in 96 out of 143,115 patients admitted to a large general hospital in New York between 1935 and 1950. In nineteen cases the diagnosis was purulent pericarditis: in fourteen of these cases the diagnosis was made at autopsy and in the remainder clinically; three of the patients were under 9 years of age.

Wilkins and associates[3] reported a case of purulent pericarditis and pleural empyema due to *H. influenzae*, type B, in a 4-year-old boy. He recovered after pericardiotomy, repeated thoracocentesis, and antibiotic therapy, with the concurrent administration of penicillin, Aureomycin, Streptomycin, and sulfonamides. Wilkins[4] stated that the patient, who at the time of writing had been under observation for three years, showed no signs of adhesive pericarditis. In his opinion, early drainage of the pericardium is indicated in such cases; this may prevent the development of adhesive pericarditis and avoid the necessity of pericardiectomy.

In a study of the literature, Wilkins and associates[3] found nine earlier reports of pericarditis caused by *H. influenzae* in children aged two to seven years. Six of the patients had died on the fourth to twelfth day of the illness, and the remaining three had recovered. Treatment consisted of pericardiotomy or pericardiocentesis; one of the surviving patients had also been given sulfonamide therapy.

As a result of the studies made by Tillett and co-workers,[5,7] and Christensen,[6] and their subsequent therapeutic use of a fibrinolytic enzyme produced by hemolytic streptococci, the possibilities of successful drainage of exudates in the body

From the Department of Medicine (Head: Professor C. Gyllenswärd), Kronprinsessan Lovisas Barnsjukhus, Karolinska Institutet, Stockholm, Sweden.

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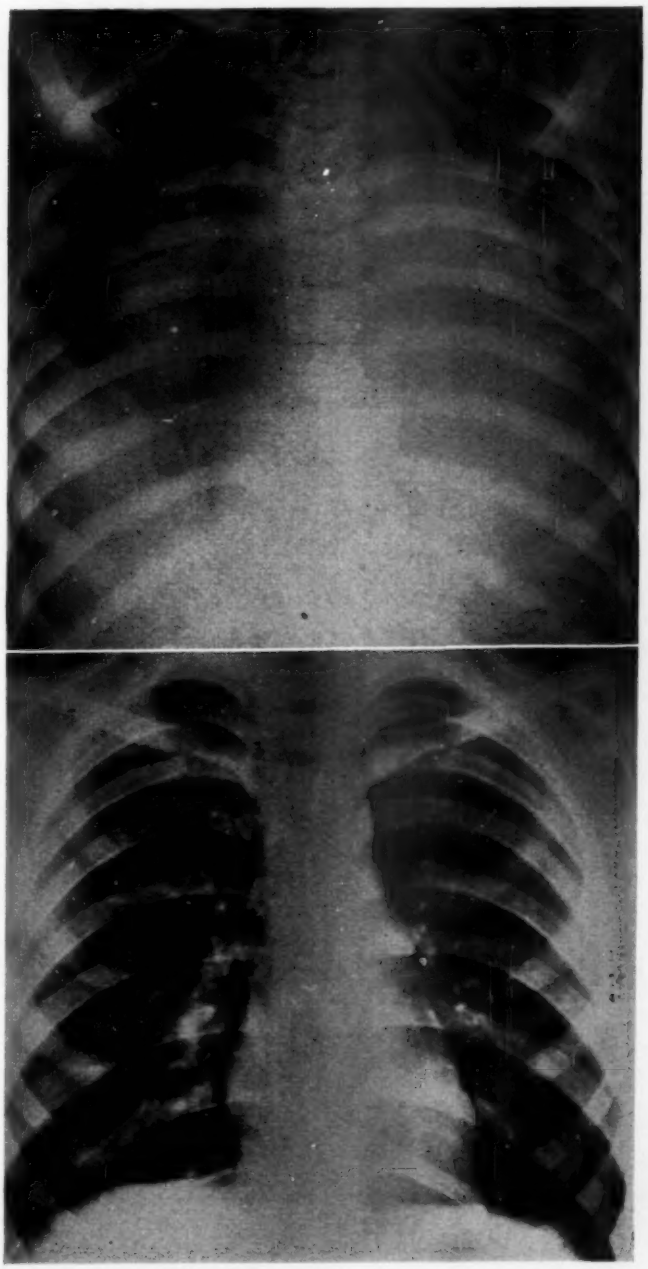
A.



B.

Fig. 1.—*A*, Roentgenogram of the chest on admission to hospital, showing the enormously enlarged cardiac shadow and bilateral, basal pleural exudate (Dr. Ulfsparre). *B*, Roentgenogram of the chest 7 months later, showing normal conditions.

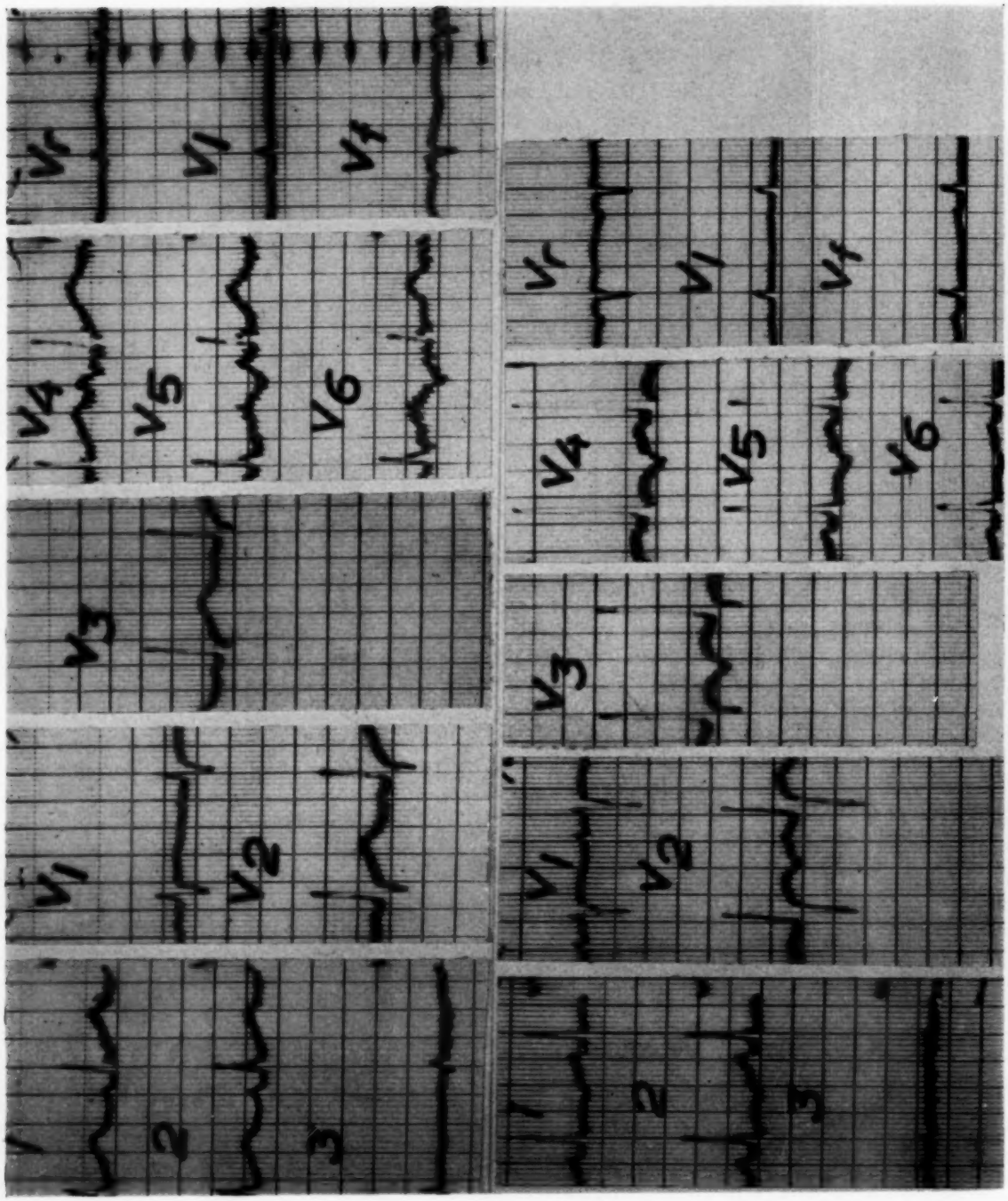
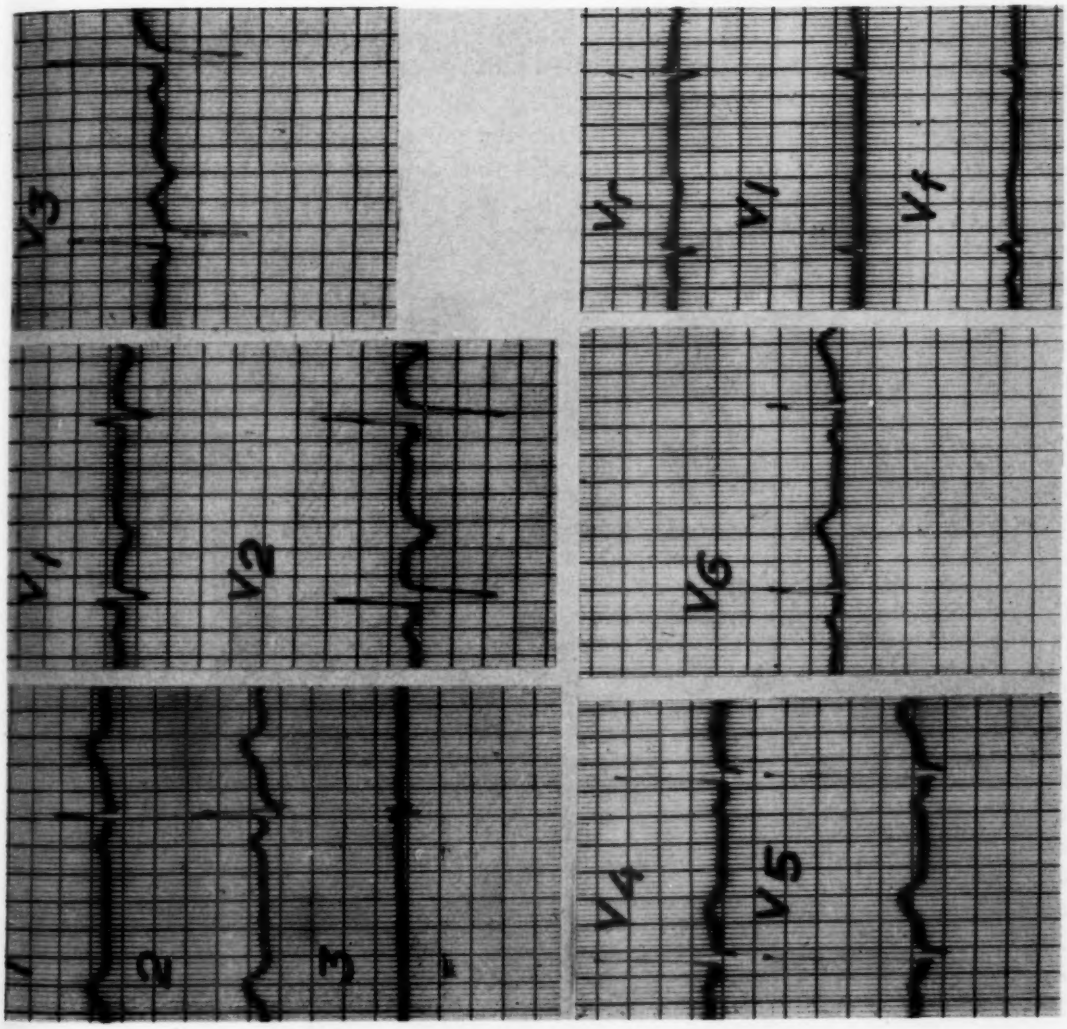


Fig. 2, *A* and *B*. *(For legend see opposite page.)*



C.

Fig. 2.—*A*, Electrocardiogram on admission to hospital, showing sinus tachycardia (135 beats per minute) but no other signs of myocardial damage (Dr. Lundberg). *B*, Electrocardiogram 6 days after admission, showing sinus tachycardia (150 beats per minute) and signs of myocardial damage: inverted T waves in standard leads and elevation of the S-T segment. *C*, Electrocardiogram 7 months after admission to hospital, showing completely normal conditions.

Fig. 2, *A* and *B*. (*For legend see opposite page.*)

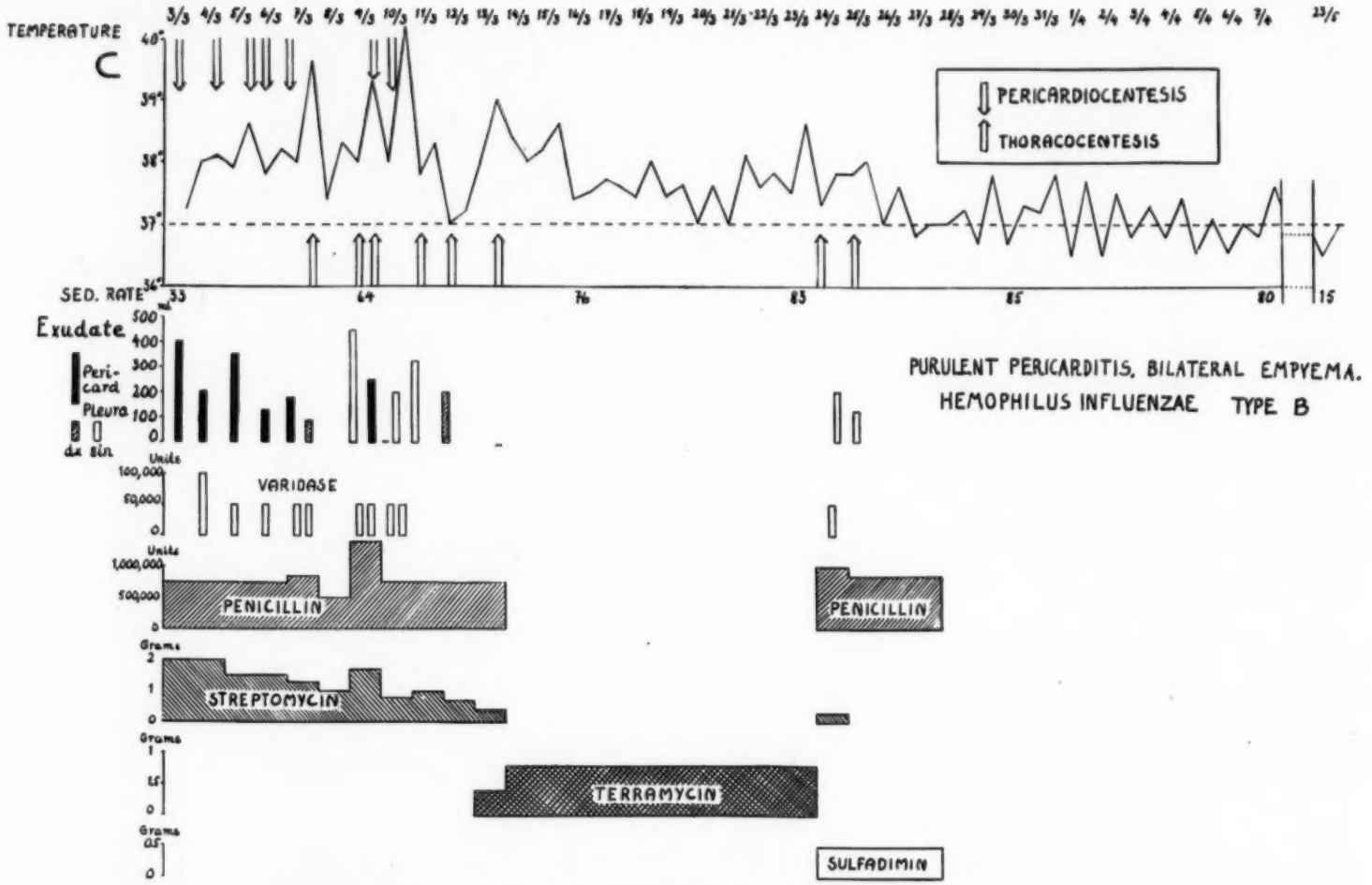


Fig. 3.—Graphic representation of the course of the patient's illness.

cavities have greatly improved. Favorable results have, for example, been reported in the treatment of empyema.[7] The use of this enzyme has also been studied in Sweden.[8] Its clinical effect is twofold. First, it dissolves the fibrin clots in the exudate, which becomes highly fluid and can therefore be aspirated without difficulty. Second, it makes it easier to check the infectious process with antibiotic therapy.

Wright and associates[9] described a case of a penetrating wound of the heart, complicated by hemopericarditis due to *Str. viridans*. Initially, no fluid could be aspirated from the pericardium; after the administration of streptokinase-streptodornase, 250 ml. of fluid exudate were withdrawn. The remainder of the fluid underwent spontaneous resorption. I have been unable to find any additional report in the available literature of the use of streptokinase-streptodornase in the treatment of purulent pericarditis. An account of a case treated in 1953 at the Medical Department of Kronprinsessan Lovisas Barnsjukhus, therefore, appears to be of interest.

CASE REPORT

A 6-year-old girl became ill with high fever and a sore throat. She was first treated at home by a general practitioner, who diagnosed an acute sore throat and prescribed oral doses of penicillin. The fever persisted and, after about 10 days, vomiting, diffuse abdominal pains, and respiratory embarrassment supervened. An acute abdominal condition was suspected, and the patient was admitted to the surgical department of the local hospital, where exudative pericarditis was diagnosed. The child was then sent to the Medical Department of Kronprinsessan Lovisas Barnsjukhus on March 3, 1953.

Physical examination on admission showed an acutely ill child, with severe dyspnea, cyanosis, an extremely rapid pulse, and cold extremities. Extensive, thin-scaled, powdery desquamation was present on the trunk and extremities, and the tongue had the strawberry appearance seen in scarlet fever. Percussion disclosed signs of bilateral pleural thickening and considerably increased cardiac dullness. The blood pressure was 105/90 mm. Hg.

The roentgenogram of the chest (Fig. 1*A*) showed considerable, generalized enlargement of the cardiac shadow and bilateral, basal thickening of the pleurae. The electrocardiogram (Fig. 2*A*) disclosed sinus tachycardia but no other abnormalities.

Laboratory findings: The blood count showed 13,200 leukocytes per cu. mm. of which 21 per cent were stab cells, 49 per cent polymorphonuclears, 22 per cent lymphocytes, 7 per cent monocytes, and 1 per cent plasma cells. The hemoglobin was 10.8 grams per 100 c.c. and the erythrocyte count 4,000,000 per 100 c.c. Urinalysis showed slight albuminuria but otherwise normal findings. No growth of hemolytic streptococci was obtained on culture of a swab from the throat. Cultures and guinea pig tests for tubercle bacilli in the pericardium and pleurae were negative.

Immediate puncture of the pericardium was made as an emergency measure, and 400 ml. of thick, yellow pus containing numerous shreds of fibrin were withdrawn. Prompt amelioration of the symptoms resulted. On bacteriologic examination of the exudate, a microorganism was isolated which was highly sensitive in vitro to penicillin, Streptomycin, sulfonamide, Terramycin, Aureomycin, and Chloromycetin. The microorganism was later identified as *Hemophilus influenzae*, type B. Antibiotic therapy was instituted on the day of admission (Fig. 3).

On the following day, aspiration was again attempted but owing to the thick shreds of fibrin, a large quantity of the viscous exudate could not be aspirated. It was therefore decided to deposit 100,000 units of streptokinase and 25,000 units of streptodornase intrapericardially, in addition to the instillation of penicillin and Streptomycin. During the eight hours following the intervention, the patient had moderate systemic disturbances and chills.

The procedure was repeated, with daily fluoroscopic control, one-half the aforementioned quantity of streptokinase-streptodornase being deposited intrapericardially on each occasion. Pericardiocentesis was performed altogether seven times, with aspiration of a thin, purulent fluid which contained no shreds of fibrin. The bilateral empyema was treated in the same way. Each injection of the enzymes was associated with febrile reactions, but they were not of such a degree as to indicate discontinuation of therapy.

Serologic analyses showed positive agglutination of *H. influenzae*, type B, in a titer of 1:8. In the course of therapy, the antistreptokinase titer in the serum was determined: 6 days after the first treatment it was 800 units, and after a further 6 days it had risen to 14,000 units.

During the first week in the hospital, the electrocardiogram showed signs of myocardial involvement; there were inverted T waves in the standard leads and elevation of the S-T segment but no other changes typical of pericarditis (Fig. 2*B*). The course of the temperature, the blood sedimentation rate, and the doses of antibiotics administered are shown in Fig. 3.

The subsequent course was satisfactory. The patient regained strength rapidly and after 12 weeks in the hospital she was discharged in good condition. The roentgenogram of the chest then showed a normal cardiac shadow but residual slight pleural thickening on the left side. The venous pressure was 7 cm. H_2O, the electrocardiogram and phonocardiogram were normal, as was the electrokymogram. The patient was readmitted to the hospital in October, 1953, for a follow-up examination. She had then started school and joined in games with no signs of cardiac decompensation. The roentgenogram of the chest (Fig. 1*B*) showed completely normal conditions. The electrocardiogram (Fig. 2*C*), phonocardiogram, electrokymogram, and venous pressure were still normal; blood analyses and urinalysis disclosed no abnormalities.

DISCUSSION

It is possible that in the case described there was a concurrent hemolytic streptococcal infection. This could have caused the symptoms reminiscent of scarlet fever (strawberry tongue and desquamation) and have contributed to the severe course of the *H. influenzae* infection. Penicillin therapy before hospitalization may have checked the streptococcal infection, with a negative culture from the throat as a result, whereas it had no effect on the *H. influenzae*.

The satisfactory outcome, despite the fact that the patient was admitted to the hospital at a relatively late stage, must be ascribed to a number of factors. One was the immediate puncture of the pericardium, which in this case had a dramatic effect. Another was the continued antibiotic therapy, with a combination of Streptomycin and penicillin, administered intramuscularly, in addition to local instillation in the pericardium and later in the empyema cavities as well. The concurrent streptokinase-streptodornase therapy undoubtedly contributed greatly to the successful results and made pericardiotomy unnecessary.

Our choice of antibiotics was motivated as follows. Penicillin and Streptomycin were among the antibiotics to which the invading organisms were sensitive in vitro. Since these antibiotics are suitable for both systemic and topical therapy and for use in conjunction with streptokinase-streptodornase, it was decided to give them as long as the invading organisms had not been identified. (A definite answer was obtained only about two weeks after the institution of therapy.) As it has been found expedient in severe infections to alternate between anti-infective agents differing in their mode of action, we substituted Terramycin after 10 days, and finally gave a combination of sulfonamide, penicillin, and Streptomycin.

When a prolonged course of streptokinase-streptodornase is given, it has

been recommended[10] to increase the dose, on account of the formation of anti-enzyme. In our patient, a rise was noted in the antistreptokinase titer from 800 units on the sixth day of treatment to 14,000 on the twelfth day. Despite this fact, we did not observe any decrease in the effectivity, although, after the initial dose of 100,000 units of streptokinase and 25,000 units of streptodornase, we subsequently gave the same dose intrapericardially on each occasion, i.e., 50,000 and 12,500 units, respectively.

It is difficult in the present case to make a long-term prognosis with respect to the development of constrictive pericarditis. No collected data are as yet available on pericarditis treated with streptokinase-streptodornase. The favorable course, with the complete absence of symptoms of cardiac decompensation, as well as the definitely negative findings in the roentgenograms of the heart, the electrocardiogram, electrokymogram and venous pressure, nevertheless, indicate that the risk of such a complication is presumably slight.

It will, however, be necessary to keep the patient under close observation. This is partly because pericardiectomy is more likely to be successful if it is performed at an early stage than if the condition is long-standing. The investigations of value in this case, in addition to roentgenograms and electrocardiograms, are studies of the venous pressure and electrokymography, which can provide early information regarding the possible onset of pericardial shrinkage.

SUMMARY

A case of purulent pericarditis and bilateral empyema caused by *H. influenzae*, type B, in a 6-year-old girl is presented. She was successfully treated with repeated pericardiocentesis and aspiration of the pleurae, and systemic and local administration of antibiotics, in combination with streptokinase-streptodornase. The prognosis with regard to possible sequelae in the form of constrictive pericarditis is discussed.

I wish to express my sincere thanks to Professor C. Crafoord and Dr. G. Ekström for valuable discussions regarding the treatment of the patient. I am also greatly indebted to Dr. E. Bengtsson of Epidemisjukhuset, Stockholm, Sweden, who made the electrokymographic investigations, and to AB. Kabi, Stockholm, for performing the antistreptokinase titrations. The other bacteriological investigations were made at the Municipal Bacteriological Central Laboratory, Stockholm, Sweden.

REFERENCES

1. Griffith, G. C., and Wallace, L.: The Etiology of Pericarditis (Abst.), International American Cardiological Congress, AM. HEART J. **37**:636, 1949.
2. Reeves, R. L.: The Cause of Acute Pericarditis, Am. J. M. Sc. **225**:34, 1953.
3. Wilkins, R. B., Jarvis, F. J., and King, R. L.: Purulent Pericarditis Due to Hemophilus Influenzae, Type B, AM. HEART J. **42**:749, 1951.
4. Wilkins, R. B.: Personal communication, 1953.
5. Tillett, W. S.: The Occurrence of Antifibrinolytic Properties in the Blood of Patients With Acute Hemolytic Streptococcus Infections, J. Clin. Investigation **14**:276, 1935.
6. Christensen, L. R.: Streptococcal Fibrinolysis: A Proteolytic Reaction Due to a Serum Enzyme Activated by Streptococcal Fibrinolysin, J. Gen. Physiol. **28**:363, 1945.
7. Tillett, W. S., Sherry, S., and Read, C. T.: The Use of Streptokinase-Streptodornase in the Treatment of Post-Pneumonic Empyema, J. Thoracic Surg. **21**:275, 1951.
8. Hedlund, P.: Streptokinas och Streptodornas, Nord. Med. **44**:1574, 1950.
9. Wright, L. T., Smith, D. H., Rothman, M., Quash, E. T., and Metzger, W. I.: The Use of Streptokinase-Streptodornase in Certain Surgical Conditions, J. Internat. Coll. Surgeons **15**:286, 1951.
10. Varidase: Streptokinase-Streptodornase. An Effective Physiological Curette, New York, 1951, Lederle Laboratories Division (with extensive bibliography).

AURICULAR CONDUCTION IN A CASE OF WANDERING AURICULAR PACEMAKER

R. WENGER, M.D., AND E. WICK, M.D.

VIENNA, AUSTRIA

WHEREAS auricular ectopic beats are found with relative frequency, the occurrence of longer periods of a second auricular rhythm is seen rarely. Such cases have been described as "wandering auricular pacemaker".[4] In the present case two different types of P waves have been observed.

We are reporting a case, in which it has been possible to localize with relative accuracy the pacemakers by means of esophageal leads and of vectorcardiography.

The electrocardiograms have been registered on a 21-year-old man, who had no previous illnesses. He had been admitted to the hospital because of chronic otitis. He never had any subjective complaints. The clinical examination revealed the presence of a cardiac arrhythmia. The electrocardiogram showed that there are two types of P waves. Fig. 1,*a* shows Lead II. There is one type of P wave, which is upright in all standard leads, in Leads V_L, V_F and in the chest Leads V_1 to V_4. The other type of P is downward in Leads II, III, V_L, and V_F, flat in V_1, downward in V_2 and isoelectric in Leads V_3, V_4, and the other chest leads of the left side.

The ventricular complexes, the S-T segments, and the T waves show no abnormalities and are unaltered during the ectopic beats.

There are mainly long periods of complexes with downward P waves, which are interrupted by shorter periods with upright P waves. The periods free from ectopic beats (of the "lower rhythm" with downward P waves) which consist of sinus beats do not have exactly the length of a varying integral multiple of one ectopic period. The periods of negative P waves terminate with a pause of about 1.3 sec., after which the complexes with positive P waves start. The periods of upright P waves change without any pause into the periods with downward P waves (Fig. 1,*i*). Sometimes there are in a long period with downward P waves, single beats with upright P waves. Also in this case a pause precedes these beats (Fig. 1,*j*).

In other instances two complexes with upright P waves are included in a long series of beats with downward P waves (Fig. 1,*k*). The rate of the periods with downward P waves is about 80, whereas that of the beats with upright P waves is about 72 per minute. The P-R intervals are 0.18 sec. for the downward and 0.20 sec. for the upright P waves.

The fact that the intervals between the periods of ectopic beats in this case are not exactly multiples having a common denominator seems to exclude the possibility of a diagnosis of auricular parasystole. Also the fact, that after each period of ectopic beats (with downward P waves) a pause of 1.3 sec. precedes the start of the sinus rhythm speaks against the assumption of a complete independence of two rhythms. We therefore think that in this case the diagnosis of a "wandering auricular pacemaker" is justified (Katz). A similar case has been described as "substituting rhythm" ("Ersatzrhythmus") by Korth.[29] The pacemaker is changing from the sinus node to a more caudally situated point in the auricles. The esophageal leads are shown in Fig. 1,*b-h*. We measure the I-R intervals (from the beginning of the rapid downstroke = intrinsicoid

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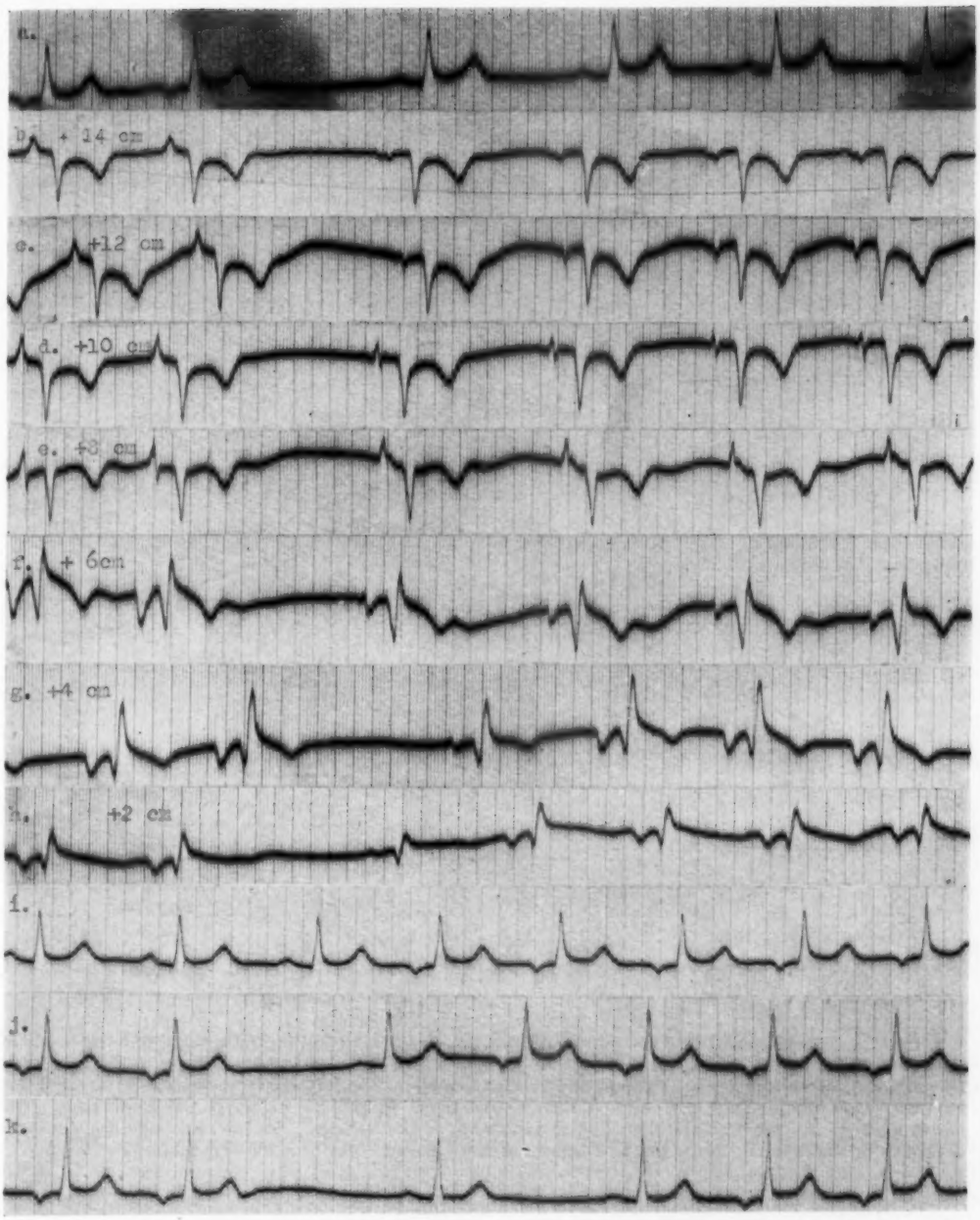

Fig. 1.—*a*, Lead II. Change of "lower" to "upper rhythm." There is a pause between the two rhythms. *b-h*, Esophageal leads, registered 14 to 2 cm. above the diaphragm. See text for explanation. *i*, Sudden change, without pause, from "upper" to "lower rhythm." *j*, One beat, belonging to the upper rhythm, is registered between runs of "lower rhythm."

deflection until the beginning of the R wave). This is correlated to the P-R interval, in order to exclude errors due to fluctuations of the atrioventricular conduction time caused by changes of heart rate. We described the meaning of this ratio $\frac{P-R}{I-R}$ in detail[22,24,25] elsewhere. The higher this ratio (the normal values are 1.2 to 2.0) is, the later the activation wave passes the point of the posterior wall of the left auricle, which lies in the vicinity of the esophageal electrode.

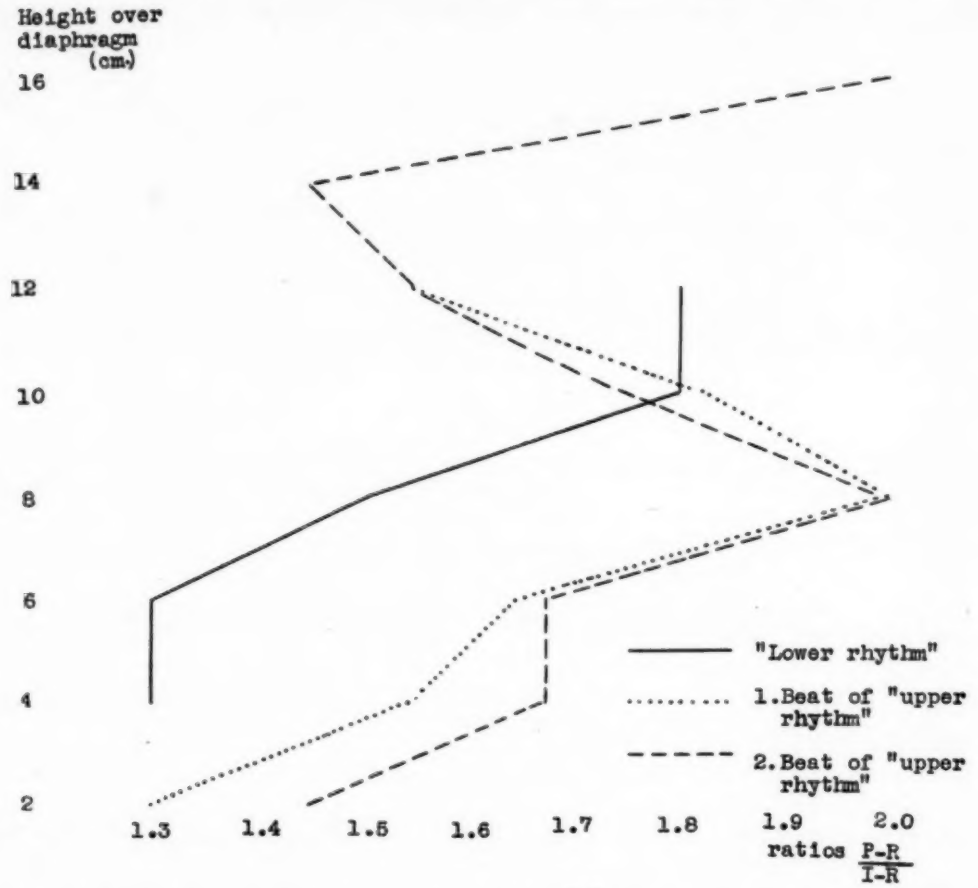

Fig. 2.—Atriodiagram. On the horizontal line are the $\frac{P-R}{I-R}$ ratios, on the vertical line the height of the various points above the diaphragm (in centimeters). The left curve corresponds to the lower rhythm. It is oblique from left below to right above, from +2 to +10 cm. above the diaphragm. This corresponds to the caudocranial direction of activation of the auricles. On the right side are the atriodiagrams of the first two beats of the "upper rhythm" shown. See text for explanation.

Esophageal electrocardiograms have been registered by means of a special electrode[23] every 2 cm. above the diaphragm. At a point 2 cm. above the diaphragm (Fig. 1,*h*) the "lower type" of P waves (downward directed in Leads II and III) does not show very distinct intrinsicoid deflections. The P waves of the "upper type" show an I-R interval of 0.14 sec. The ratio is 1.44. The values of the I-R intervals and of the corresponding ratios for both types of P waves and for all levels of the esophagus, where intrinsicoid deflections are registered, are shown in Table I. The pattern of the two types of P waves differs also in the esophageal leads.

The "lower type" shows downward directed P waves in the "lower" esophageal leads (2 to 6 cm. over the diaphragm, Fig. 1,*h*, *g*, and *f*), diphasic P waves 8 cm. above the diaphragm (Fig. 1,*e*) and positive complexes in the "high" levels 10 to 14 cm. above the diaphragm (Fig. 1, *d*, *c*, *b*).

The I-R intervals become shorter from +2 to +12 cm. above the diaphragm (0.14 to 0.10 sec.), the ratio $\frac{P-R}{I-R}$ shows a corresponding prolongation (1.29 to 1.8).

The upper type of P wave shows various patterns in different esophageal levels. Also the I-R intervals and the $\frac{P-R}{I-R}$ ratios change (Table I) at various heights. We also constructed the atriodiagrams (Fig. 2) for both types of P waves by using the distances from the diaphragm to the electrode as ordinate and the ratio $\frac{P-R}{I-R}$ as abscissa. The first beat after the pause shows an atriodiagram, which starts at a point, which lies at the left side of the diagram similar to the atriodiagram of the "lower type." The later beats show minor differences of timing; after the fifth beat the time relations are stable and the atriodiagrams of the following beats of this type no longer show any change.

TABLE I

HEIGHT OVER THE DIAPHRAGM (CM.)	"LOWER RHYTHM" (P-R 0.18)		"UPPER RHYTHM" (P-R 0.2 SEC.)									
			1. BEAT		2. BEAT		3. BEAT		4. BEAT		5. BEAT	
	I-R	$\frac{P-R}{I-R}$	I-R	$\frac{P-R}{I-R}$	I-R	$\frac{P-R}{I-R}$	I-R	$\frac{P-R}{I-R}$	I-R	$\frac{P-R}{I-R}$	I-R	$\frac{P-R}{I-R}$
2	0.14	1.29	—	—	0.14	1.44	0.14	1.44	0.14	1.44	0.14	1.44
4	0.14	1.29	0.13	1.54	0.12	1.67	0.12	1.67	0.12	1.67	0.125	1.6
6	0.14	1.29	0.12	1.67	0.12	1.67	0.12	1.67	0.13	1.54	0.14	1.44
8	0.12	1.50	0.10	2.0	0.10	2.0	0.105	1.9	0.11	1.82	0.12	1.67
10	0.10	1.80	0.11	1.82	0.115	1.74	0.125	1.6	0.13	1.54	0.14	1.44
12	0.10	1.80	0.13	1.54	0.13	1.54	0.14	1.44	0.14	1.44	0.14	1.44
14	—	—	—	—	0.14	1.44	0.14	1.44	0.14	1.44	0.14	1.44
16	—	—	—	—	0.10	2.0	0.10	2.0	0.10	2.0	0.10	2.0

The atriodiagram of the "lower type" of P wave shows between 2 and 10 cm. above the diaphragm an oblique curve from left below to right above, corresponding to the diminution of the I-R intervals in the caudocranial direction. The "upper type" does not show such a regular course for a longer distance but shows several spikes to the right in various heights.

The vectorcardiogram, registered by the method of Polzer and Schuhfried[28] is shown in Fig. 3. In the frontal plane (Fig. 3,*A*) the integral vector of P of the "upper type" is directed downward and slightly to the left (first three complexes). After one beat of intermediate form there is a change to the "lower rhythm." The integral vector of the P waves of this rhythm is directed cranially. In the horizontal plane the "lower rhythm" shows auricular vector loops, which are directed posteriorly (first complex of Fig. 3,*B*), whereas the integral vector of the upper rhythm is directed anteriorly (last four complexes of Fig. 3,*B*). In the sagittal plane (Fig. 3,*C*) the same change of direction of the P vectors may be observed. They are directed downward and slightly anteriorly during the "upper rhythm" (first two complexes of Fig. 3,*C*), upward and slightly posteriorly during the "lower rhythm" (last 4 complexes of Fig. 3,*C*). In both instances one beat after the suppression of the first type shows an intermediate pattern of the auricular vectorcardiogram.

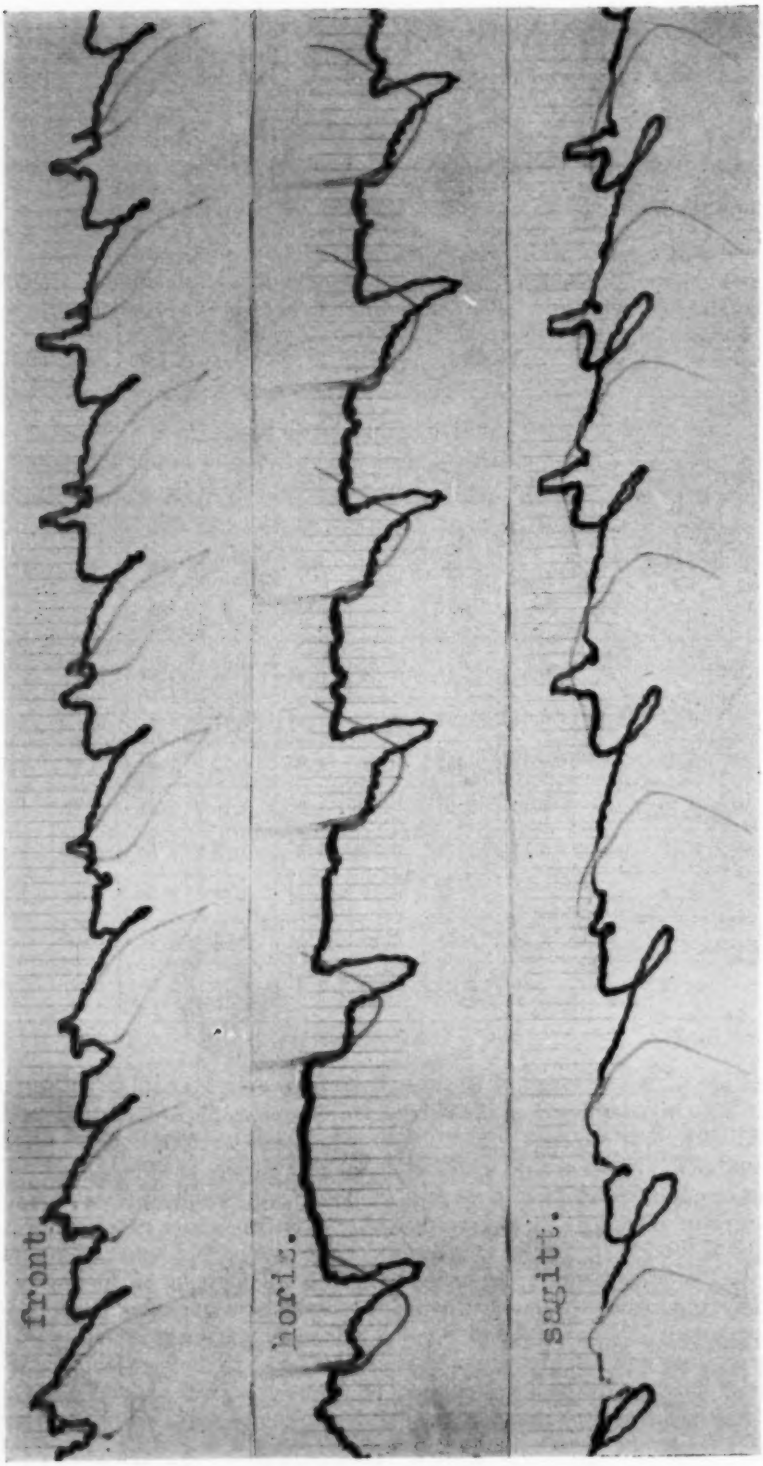

Fig. 3.—*A*, Frontal vectorcardiogram. The first three beats belong to the "upper rhythm." The auricular vector loops are directed downwards and slightly to the left. The last three complexes are examples of the "lower rhythm." The auricular integral vector is directed upward and slightly to the right. *B*, Horizontal vectorcardiogram. The first complex is an example of the lower rhythm (auricular vector loop directed posteriorly). All the following complexes belong to the "upper rhythm." The vector loops are directed anteriorly. *C*, Sagittal vectorcardiogram. The first two complexes belong to the "upper rhythm." The vector loops of the P waves are directed downward and slightly anteriorly. The last four complexes are examples of the "lower rhythm" and show auricular vectorcardiograms which are directed upward and posteriorly.

We also examined the effect of sympathicomimetic drugs and of irritation of the vagus on this arrhythmia. This will be described briefly. After Adrenalin (1 c.c. of a 1:1,000 solution, subcutaneously) the upper rhythm disappeared for 20 minutes almost completely. The heart rate accelerated to 110 beats per minute. Only 4 minutes after the injection, a short run of complexes with upright P waves could be registered. On carotid sinus pressure the "lower rhythm" changed regularly to an "upper rhythm." On release of the pressure the "lower rhythm" came back immediately. After exercise and pressure on the eye bulbs the reactions were not uniform.

DISCUSSION

The upright P waves seem to have their origin in the sinus node. The downward directed P waves show a P-R interval of 0.18 sec. This speaks against the assumption that they might arise in the atrioventricular node (so-called "upper nodal rhythm"). The relatively long P-R interval strongly supports the concept that these beats have their origin in the caudal part of the auricles. At the present stage of our knowledge we would not try to exclude with certainty the presence of a so-called "coronary sinus rhythm" in this case. This rhythm also shows a relatively unaltered P-R interval.

The pattern of the auricular complexes of the esophageal leads shows a change from downward directed deflections in the lower leads (Fig. 1, *h-f*) to upward directed deflections in the higher levels, as far as the "lower rhythm" is concerned. Correspondingly, the I-R intervals decrease in caudocranial direction. This corresponds to a caudocranial way of activation. The $\frac{\text{P-R}}{\text{I-R}}$ ratios diminish in this direction and the atriodiagram (Fig. 2, left curve) shows (in the portion from 2 to 10 cm. above the diaphragm) a direction from left below to right above. We were able to observe the same pattern in cases of nodal rhythm.[26] In this case these findings, as well as the form of the vectorcardiogram, seem to be due to the fact, that the stimulus of the "lower rhythm" originates in the caudal part of the auricles. It would be very difficult to try to decide the question if the "lower rhythm" originates in the lower part of the right or of the left auricle.

In our opinion the pattern of the esophageal electrocardiogram is mainly influenced by the activation of the left auricle. But there is no doubt that in the lower levels of the esophagus the right auricle may also play an important role in causing the respective electrocardiographic patterns.[10,24] After the last beat of the "lower rhythm" there is a pause, and then the "upper rhythm" begins. The first beat of the upper rhythm in the esophageal electrocardiograms shows in some levels a slightly different pattern in contrast to the following beats. The form of the esophageal electrocardiogram does not show an oblique curve as it has been observed in the "lower rhythm." The atriodiagram of this rhythm shows an irregular pattern. It is remarkable that the curve of the atriodiagram of the first beat after the pause begins at a point 2 cm. above the diaphragm as far to the left as that of the "lower rhythm" (dotted line). This speaks in favor of the assumption that the first beat after the pause still arises at a very caudally situated point of the auricles. The atriodiagrams of the following third to fourth

beats do not correspond each one to the other in each level. This may be due to slight changes of the point of origin, until the definite sinus rhythm is established again. It also may be caused by functional reasons, due to the condition of the sinus node or of the auricular musculature after the termination of the faster and slower rhythm. After five beats no further changes of the atriodiagrams occur.

The irregular type of the atriodiagram of the "upper rhythm" speaks in favor of the assumption that its origin is not situated in the left, but in the right auricle.

SUMMARY

A case of wandering auricular pacemaker is presented. The evaluation of esophageal leads and of auricular vectorcardiograms further elucidates the path of the stimuli. Whereas one rhythm seems to originate in the caudal part of the auricles, the other one has its origin in the sinus node. At least the first beat after the ectopic auricular rhythm seems to have still a caudally situated point of origin. A few beats are necessary to re-establish a regular pattern of sinus rhythm. The etiologic factors, which may be responsible for this, are discussed. Adrenalin caused an almost complete suppression of the (slower) sinus rhythm. Vagal stimulation (by carotid sinus pressure) in all instances suppressed the ectopic auricular rhythm. It came back immediately after release of pressure.

REFERENCES

1. Faltitschek, F., and Scherf, D.: Klinischer Beitrag zur Parasystoliefrage, Wien. Arch. f. inn. Med. **23**:269, 1932.
2. Holzmann, M.: Beitrag zur Kenntnis der Parasystolie, Helvet. med. acta **1**:723, 1935.
3. Jervell, A.: Ein Fall von Vorhofparasystolie, Acta med. scandinav. **79**:239, 1932.
4. Katz, L. N.: Electrocardiography, ed. 2, Philadelphia, 1946, Lea & Febiger.
5. Katz, L. N., Eschelbacher, J. L., and Strauss, S.: An Unusual Case of Auricular Parasystole Showing Exit Block, Am. Heart J. **14**:571, 1937.
6. Kaufmann, R., and Rothberger, C. J.: Beiträge zur Kenntnis der Entstehungsweise extrasystolischer Arrhythmien. II., Ztschr. f. d. ges. exper. Med. **7**:199, 1919.
7. Kaufmann, R., and Rothberger, C. J.: Beiträge zur Kenntnis der Entstehungsweise extrasystolischer Arrhythmien. IV., Ztschr. f. d. ges. exper. med. **11**:40, 1920.
8. Pick, A., and Fishman, A. P.: Observations in Heart Block. Supernormality of A-V and Intraventricular Conduction and Ventricular Parasystole Under the Influence of Epinephrine, Acta Cardiol. **5**:270, 1950.
9. Pick, A.: Parasytole, Circulation **8**:243, 1953.
10. Prinzmetal, M., Corday, E., Brill, I. C., Oblath, R. W., Kruger, H. E., and others: The Auricular Arrhythmias, Springfield, Ill., 1952, Charles C Thomas, Publisher.
11. Rosenblüth, E., and Winterberg, H.: Ueber den direkten Nachweis der Austrittsblockierung bei einem Fall von Parasystolie, Wien. Arch. f. inn. Med. **16**:333, 1929.
12. Rothberger, C. J.: Ueber Extrasystolen und das Hervortreten der Automatie untergeordneter Zentren, Klin. Wchnschr. **43**:2150, 1922.
13. Rothschuh, K. E.: Elektrophysiologie des Herzens, Darmstadt, 1952, Dr. Dietrich Steinkopff.
14. Schaefer, H.: Das Elektrokardiogramm, Berlin, Göttingen und Heidelberg, 1951, J. Springer.
15. Scherf, D., and Schott, A.: Parasystolie durch einfache Interferenz mit Uebergang in Bigeminie, Klin. Wchnschr. **9**:2191, 1930.
16. Scherf, D., and Boyd, L. J.: Three Unusual Cases of Parasystole, Am. Heart J. **39**:650, 1950.
17. Scherf, D.: Zur Entstehungsweise der Extrasystolen und der extrasystolischen Allorhythmien, Ztschr. f. d. ges. exper. Med. **51**:816, 1926.
18. Scherf, D., Chick, F. B., Scharf, M. M., and Terranova, R.: Further Studies on Experimental Parasystole and Extrasystoles in Groups, Proc. Soc. Exper. Biol. & Med. **77**:28, 1951.

19. Scherf, D.: Experimental Parasystole, Am. Heart J. **42**:212, 1951.
20. Singer, R., and Winterberg, H.: Extrasystolen als Interferenzerscheinung, Wien. Arch. f. inn. Med. **1**:391, 1920.
21. Wenckebach, K. F., and Winterberg, H.: Die unregelmässige Herztätigkeit, Leipzig, 1927, W. Engelmann.
22. Wenger, R.: Die diagnostische Bedeutung des Oesophagus-Elektrokardiogramms, Wien. Ztschr. inn. Med. **28**:490, 1947.
23. Wenger, R.: Eine neue Oesophaguselektrode, Cardiologia **15**:363, 1949-1950.
24. Wenger, R., Hofmann-Credner, D., and Hörtnagl, W.: Ueber die Reizleitungsverhältnisse in den Vorhöfen. Direkte und halbdirekte elektrokardiographische Ableitungen am menschlichen Herzen. I., Ztschr. Kreislaufforsch. **39**:653, 1950.
25. Wenger, R., and Hofmann-Credner, D.: Observations on the Auricles of the Human Heart by Direct and Semidirect Electrocard'ography, Circulation **5**:870, 1952.
26. Wenger, R.: Caudocranial Conduction in the Left Auricle in Nodal Rhythm and in Nodal Ectopic Beats, Brit. Heart J. **16**:87, 1954.
27. Winterberg, H.: Extrasystolen als Interferenzerscheinung, Wien. Arch. f. inn. Med. **6**:251, 1923.
28. Polzer, K., and Schuhfried, F.: Ein Beitrag zur Ableitung des Vektorkardiogramms, Wien. med. Wchnschr. **101**:406, 1951.
29. Korth, C.: Klinische Elektrokardiographie, München und Wien, Urban und Schwarzenberg, 1952.

CASE REPORTS OF TWO PRIMARY CARDIAC NEOPLASMS

ROBERT F. MARONDE, M.D.

PASADENA, CALIF.

AN excellent summary on the subject of cardiac tumors has been recently published.[1] The present report was prepared because the author had the opportunity to observe the clinical course of two cases of primary tumors of the left auricle. Both cases were studied rather closely. If the diagnosis could be made in the future, surgical treatment might be feasible. There were certain features of these cases that would indicate that such a diagnosis can be made with reservation.

CASE REPORTS

CASE 1.—C. H., a 51-year-old white male was first seen in August, 1951. While on his vacation, he developed viselike precordial pain which lasted between one and two hours. He was admitted to a hospital with the diagnosis of coronary occlusion, but he signed out of the hospital against consent on the same day and returned to his home where he was seen by his family physician. At that time he felt well and he had no pain. The patient was seen by the author on the first day of this illness. A review of the electrocardiogram taken in the hospital showed it to be normal in all respects. Serial electrocardiograms and sedimentation rates were taken over the next week, and these were normal on each occasion. Bed rest was no longer advised, but two days after the patient became ambulatory dyspnea developed. Examination at this time revealed a blood pressure of 146/88 mm. Hg. The cardiac apex impulse was palpable 8.0 cm. to the left of the mid-sternal line in the fifth intercostal space. The mid-clavicular line was 9.0 cm. The cardiac rhythm was regular, and no murmurs were heard. The pulmonic second sound was equal to the aortic second sound. Fine, inspiratory moist râles were heard at both lung bases posteriorly. Questionable left-auricular enlargement was seen fluoroscopically in the right anterior oblique view. There were no peripheral edema or abnormal venous distention. A diagnois of heart disease of unknown etiology was made. The patient was digitalized with some improvement of the dyspnea, and he was then referred back to his family physician.

Three and one-half months later upon re-examination, it was found that the improvement which followed the administration of the digitalis lasted approximately two weeks. The dyspnea had then recurred, and it had progressed in intensity. A twenty-pound-weight loss had taken place over this period of time. Diuretics in adequate amounts and increased digitalis dosage had resulted in no relief of symptoms. Fine, moist inspiratory râles were present throughout both lung fields and marked distention of the neck and arm veins was present. The liver edge was palpable 4.0 cm. below the right costal margin at the mid-clavicular line, and it was slightly tender. A harsh systolic murmur was now present which was maximal at the fourth left intercostal space just to the left of the sternum. A rumbling, late diastolic, crescendo apical murmur, which was not transmitted, was also present. The pulmonic second sound was loud and snapping. The patient was hospitalized, and an electrocardiogram was taken which showed only slight left-axis

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Present address: 960 E. Green Street, Pasadena, Calif.

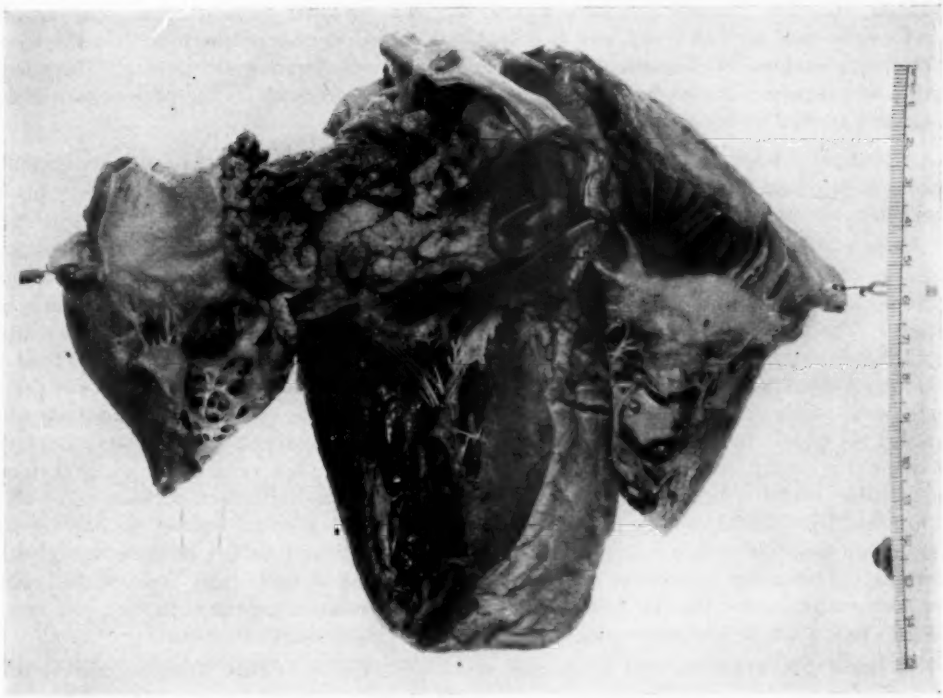

Fig. 1.—Case 1. Myxosarcoma of the left auricle.

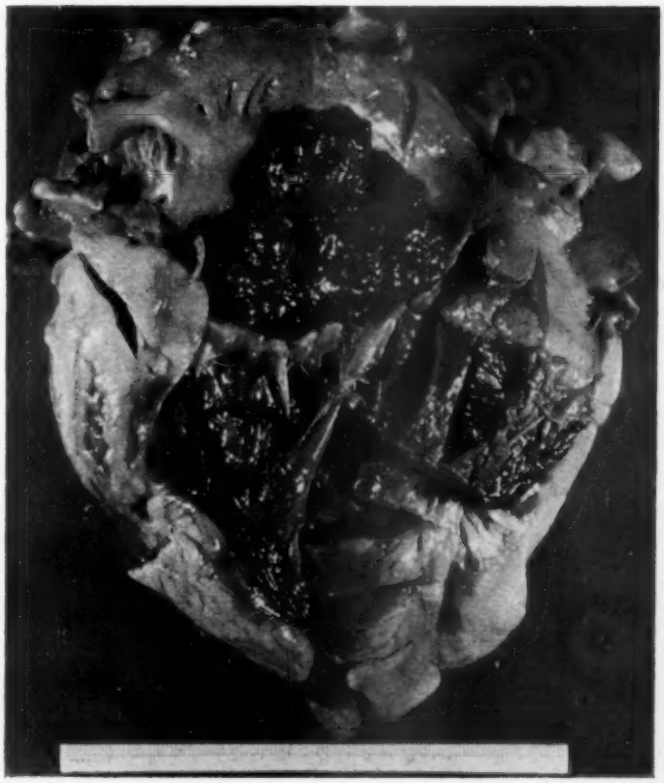

Fig. 2.—Case 2. Myxoma of the left auricle.

deviation. Cardiac fluoroscopy showed selective left-auricular enlargement. The cardiac-thoracic ratio on a six-foot x-ray was 16.5 to 33 which was considered normal. On the second hospital day abdominal distention, absent peristalsis, and vomiting developed. The cardiac rhythm was regular. A diagnosis of mesenteric embolism was made. The patient was in deep shock, and he died within a few hours.

At *autopsy* a primary tumor of the left auricle was found (Fig. 1). This was connected by a small pedicle and the pathologist reported the tumor as a myxosarcoma. Emboli to the left renal artery and the superior mesenteric artery were also present.

CASE 2.—R. M. S., a 38-year-old white female was first seen in February, 1952, because of dyspnea. The blood pressure on physical examination was 112/82 mm. Hg, and slight distention of the neck veins was present. Fine, moist, inspiratory râles were heard at both lung bases posteriorly. The cardiac apex impulse was palpable 0.5 cm. outside the left mid-clavicular line in the fifth intercostal space. The rhythm was regular. The pulmonic second sound was loud and snapping. A late diastolic rumbling apical murmur which had a crescendo quality was present at the apex. This murmur was not widely transmitted. A Grade 3 systolic apical murmur which was also not widely transmitted was heard. The electrocardiogram showed right-axis deviation. No other abnormalities were present. A diagnosis of rheumatic heart disease with mitral stenosis and possible mitral insufficiency was made. The patient was digitalized without relief of her symptoms. Hospitalization was carried out and during her hospital course she had repeated episodes of ventricular tachycardia. Digitalis was discontinued, and quinidine was given to tolerance. This failed to prevent the short, repeated bouts of ventricular tachycardia. X-ray and fluoroscopic studies showed definite selective left auricular enlargement in the right anterior oblique view. The patient died suddenly from a massive pulmonary embolism.

At *autopsy* a myxoma of the left auricle was found (Fig. 2). This tumor was connected to the auricular wall by a thin pedicle.

SUMMARY

Two cases of a primary tumor of the left auricle have been presented in the hope that by the accumulation of clinical data on such cases more accuracy in diagnosis may eventually be possible. Both patients presented findings suggestive of rheumatic heart disease with mitral stenosis and cardic decompensation. They were atypical, however, in that they failed to respond to the initial therapy for congestive heart failure, and their illness progressed rather rapidly in spite of such therapy.

REFERENCE

1. Prichard, R. W.: Tumors of the Heart, Arch. Path. **51**:98, 1951.

TOTAL ANOMALOUS PULMONARY VENOUS DRAINAGE

GEORGE MILLER, CAPTAIN, MC, USA, AND
BYRON E. POLLOCK, COLONEL, MC, USA

SAN FRANCISCO, CALIF.

IN 1942, Brody[1] surveyed the literature and reported on 106 cases of anomalous pulmonary venous drainage, in thirty-eight of which the pulmonary drainage was completely to the right atrium or its tributaries. In all instances the diagnosis was established at necropsy. More recently, numerous cases of partial anomalous venous drainage have been diagnosed ante mortem on the basis of evidence obtained by angiocardiography and, more often, by cardiac catheterization.[2-7]

In 1952, Healy[8] was able to review a total of sixty-one cases of total anomalous pulmonary venous drainage, but in only four of these cases did the patient live beyond ten years of age. Since then, Snellen and Albers[9] have emphasized the clinical picture of this condition, which is often characteristic. They reported four cases, two of which were in adults. Other recent reports indicate that the condition will be more frequently recognized in the future.[7,10,11]

Since total anomalous pulmonary venous drainage may often be recognized clinically and is potentially completely correctible by surgery, we are reporting an additional case with angiocardiograms and cardiac catheterization findings.

CASE REPORT

The patient was a 24-year-old soldier who was admitted to Letterman Army Hospital on June 20, 1952, for investigation of a "mediastinal mass" which had been noted on a routine roentgenogram taken prior to his separation from the Army. At the time of admission, he had served in the Army for three years and ten months as a lineman in the Signal Corps. Although the patient had no complaints and had participated in competitive sports while in high school, he stated that he did get somewhat more short of breath on exertion than his associates. At no time, however, did he have orthopnea, hemoptysis, or peripheral edema. At the age of five, his family physician told his mother that the patient had a large heart but he never required medical care subsequently. He was not aware of having cyanosis or clubbing.

Physical Examination:—His height was 69½ inches; weight 170 pounds; temperature 98.6° F.; respirations 16, pulse 78; blood pressure 125/86 mm. Hg. The patient was a muscular, well-nourished male who had mild but definite cyanosis of his fingers, toes, lips, and ears, together with clubbing of his fingers and toes. Although his heart appeared enlarged to the left with the point of maximal impulse in the fifth intercostal space just outside the mid-clavicular line, there was also a heaving thrust more medially. No thrills were present. There was a Grade 2, rough,

From the Cardiovascular Service of Letterman Army Hospital, San Francisco, Calif.
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blowing systolic murmur heard over the entire precordium but with maximal intensity in the third and fourth left intercostal spaces parasternally. A faint, short, diastolic murmur was also heard in this area. The remainder of the examination was essentially normal.

Laboratory studies revealed a leukocyte count of 9,300 per c. mm. with a normal differential; hemoglobin, 20.8 gram per cent; red blood cell count, 6,020,000 per c. mm.; hematocrit, 67 per cent. The serologic test for syphilis was negative. The venous pressure in the median basilic vein was 12.5 cm. saline, and the Decholin circulation time was 7 seconds. The electrocardiogram showed an incomplete right bundle branch block (Fig. 1). A roentgenogram of the chest (Fig. 2) showed that the heart had an increased transverse diameter. The main pulmonary artery segment was prominent and the lung fields showed increased vascular markings. In the superior mediastinum, there was a large ovoid shadow bulging into both lung fields. Fluoroscopy in the oblique positions revealed that the cardiac enlargement was caused by right auricular and right ventricular enlargement. The pulmonary artery branches showed expansile pulsation. The borders of the dense area in the superior mediastinum were quietly pulsatile and roentgenkymograms showed that these pulsations were not in phase with those of the aorta or pulmonary artery.

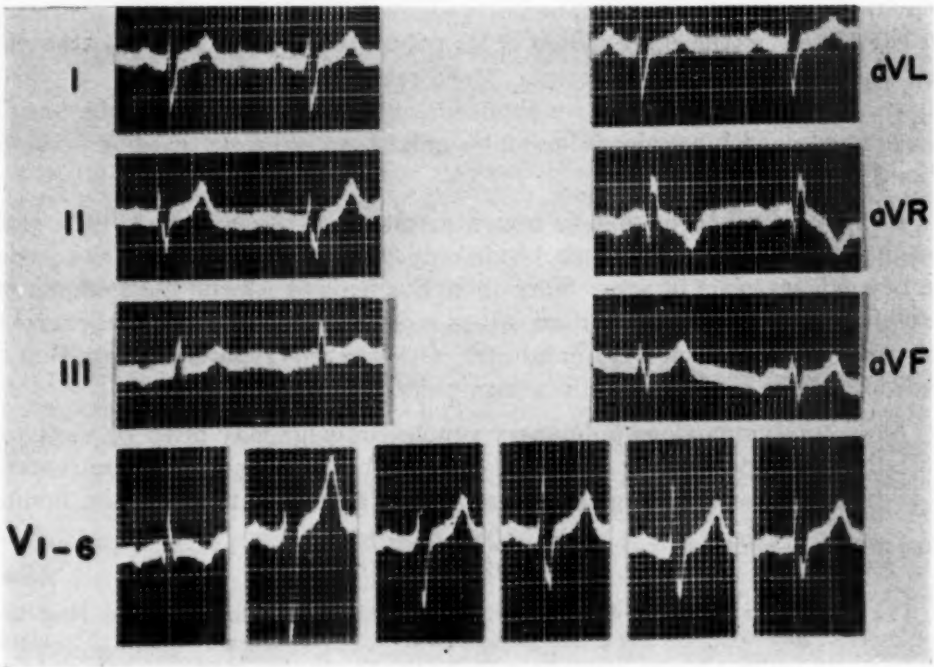

Fig. 1.—Electrocardiogram showing incomplete right bundle branch block.

Angiocardiography was performed on July 7, 1952. Commencing 4 seconds after the injection of 50 c.c. of 70 per cent Diodrast, eight films were taken at 1½-second intervals in the anteroposterior projection. The first film (Fig. 3) showed that the right portion of the superior mediastinal shadow was formed by a markedly dilated superior vena cava. In addition, the right atrium and right ventricle were dilated, and there was dye present in the pulmonary arteries, left atrium, and the arch of the aorta. The third film showed filling of the pulmonary veins (Fig. 4), and in the fourth film (Fig. 5) a large pulmonary vein could be seen coursing from the right hilar region across the midline to be joined by a large vein from the left hilar region and then ascending to join the lower, left portion of the superior mediastinal shadow. There was evidence of revisualization of the superior vena cava and the right-sided chambers in films 4 to 8, with Diodrast present in the pulmonary veins in all of these films. These angiograms are interpreted as follows: there is a large dilated right superior vena cava and dilatation of the right atrium, right ventricle, and pulmonary arteries. There is a communication between the right atrium and left

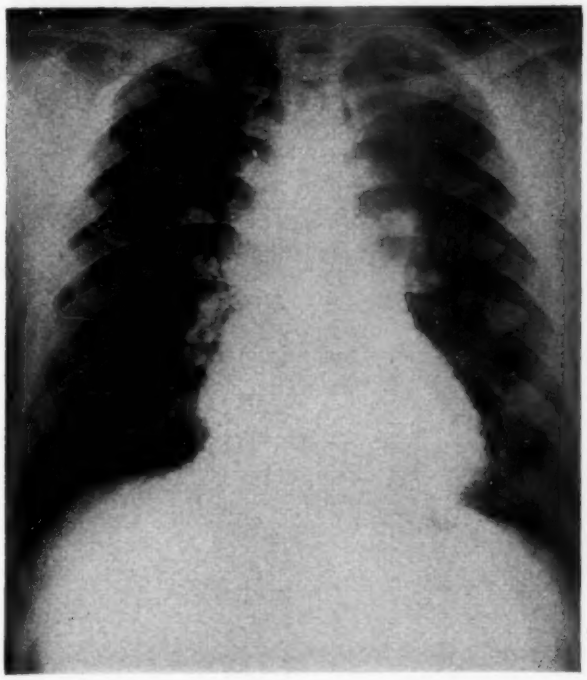

Fig. 2.—Chest roentgenogram demonstrating the large ovoid shadow in the superior mediastinum which forms a "figure-of-8" appearance with the heart.

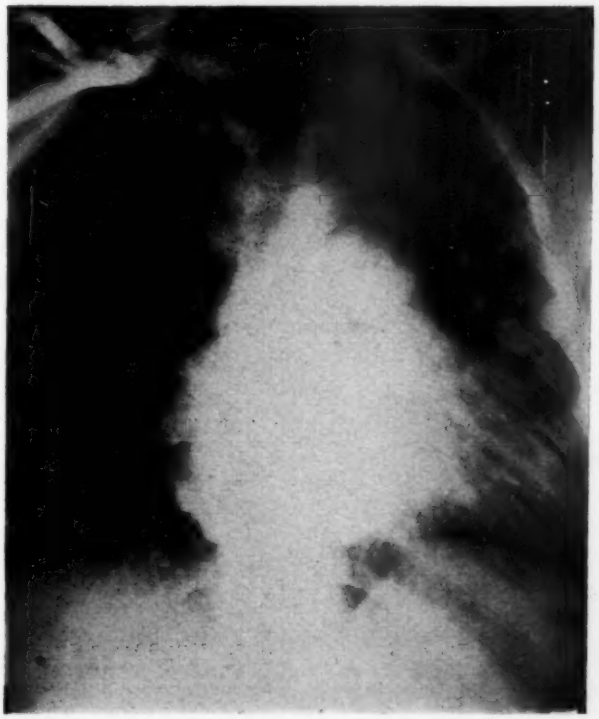

Fig. 3.—Angiocardiogram taken four seconds after the injection of Diodrast. There is dye present in the right superior vena cava, right atrium, right ventricle, pulmonary artery tree, left atrium, and arch of the aorta.

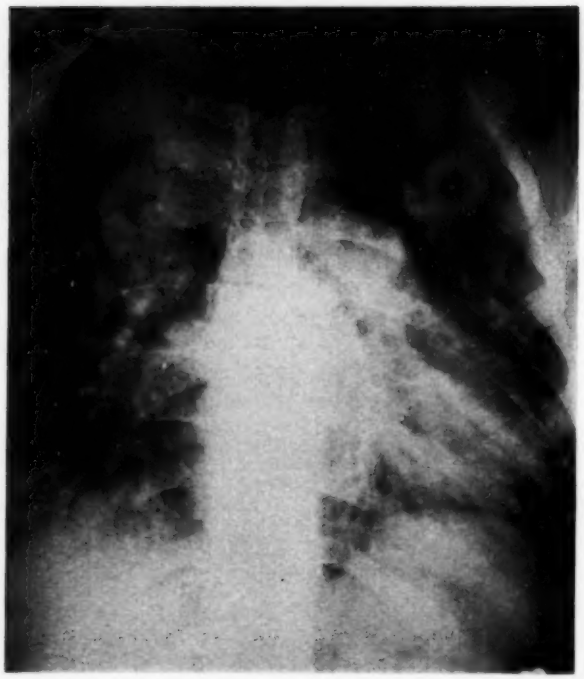

Fig. 4.—Seven seconds after dye injection, there is evidence of beginning pulmonary venous filling.

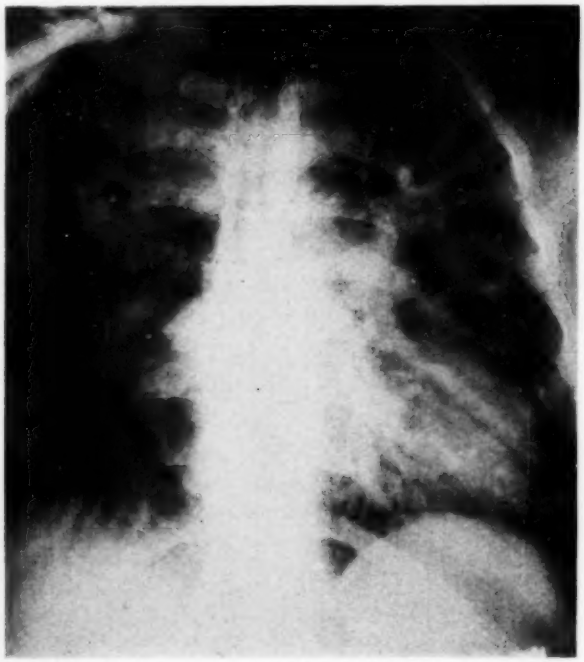

Fig. 5.—Eight and one-half seconds after dye injection; two large pulmonary veins may be seen joining just before entering the large common pulmonary venous trunk which forms the left lateral portion of the superior mediastinal shadow seen in Fig. 1. There is reopacification of the right superior vena cava.

atrium, and all of the pulmonary veins apparently are draining to the right superior vena cava via the left innominate vein. The superior mediastinal shadow present in the ordinary chest roentgenogram is formed by the large dilated superior vena cava on the right and by the common pulmonary venous trunk on the left.

After being discharged from the Army, the patient was seen at Michael Reese Hospital in Chicago where cardiac catheterization* was performed on Nov. 27, 1952. The results are shown in Table I. There was evidence of a marked left-to-right shunt into the right superior vena cava with oxygen saturation 99.3 per cent at one site in the right superior vena cava. There was evidence of a right-to-left shunt also, with the peripheral arterial blood 87 per cent saturated with oxygen. The oxygen contents of the blood samples obtained from the right atrium, right ventricle, and pulmonary artery were similar and slightly higher than those present in the brachial artery. The pressures obtained at rest during catheterization were normal. On performing exercise, at which time the patient's oxygen consumption was 262 cc./min./m,^{2} there was a slight rise in the pulmonary artery pressure to a mean of 25 mm. Hg.

TABLE I

SITE	OXYGEN CONTENT (VOL. %)	OXYGEN SAT'N (%)	PRESSURE (MM. HG)
Innominate vein	23.2	78.9	——
Right superior vena cava	29.2	99.3	——
Right superior vena cava	27.2	92.5	——
Right superior vena cava	25.2	85.7	——
Inferior vena cava	21.4	72.8	——
Right atrium: high	28.4	95.7	——
Right atrium: mid	27.2	92.5	Mean = 3
Right atrium: low	27.5	93.5	——
Right ventricle: low	26.8	91.2	——
Right ventricle: mid	27.6	93.9	25/5
Right ventricle: high	27.3	92.9	——
Main pulmonary artery	26.7	91.0	22/8 (Mean = 15)
Main pulmonary artery	27.2	92.5	——
Right pulmonary artery	26.8	91.2	——
Right pulmonary artery	27.4	93.2	——
"Pulmonary venous capillary"	——	——	Mean = 6
Brachial artery	25.4	86.4	100/62 (Mean = 75)

Oxygen capacity of brachial artery blood = 29.4 vol. per cent
Oxygen consumption at rest = 241 c.c./min. (125 c.c./min./m^2 body surface)
Systemic blood flow* = 6.0 L/min. (3.2 L./min./m^2 B.S.)
Total pulmonary blood flow = 11 L/min.
Effective pulmonary blood flow = 3.1 L/min.
Left-to-right shunt = 7.9 L/min.
Right-to-left shunt = 2.9 L/min.

*The calculations of flows and shunts in this case can only be considered as approximations. Since a true mixed venous blood sample was not obtained, the sample from the inferior vena cava was used to calculate peripheral and effective pulmonary blood flow.

DISCUSSION

The embryology of anomalous pulmonary veins has recently been reviewed by Edwards[12] and will not be discussed in this report.

In order for life to exist in cases of total anomalous pulmonary venous drainage, there must be a right-to-left shunt. All cases so far reported have had

*Dr. L. N. Katz, Chicago, Ill., kindly provided us with the catheterization data.

a patent foramen ovale while some have had additional anomalies.[1,11] If the interatrial defect is too small, there will be inadequate peripheral blood flow to support life.[13] If the defect were large, the right-to-left shunt and, therefore, peripheral blood flow would be increased. A very large atrial septal defect, however, might not be beneficial, for while the peripheral blood flow would probably be increased, there would be concomitantly a decreased pulmonary flow. Thus an increased volume of venous blood returning from the periphery would mix with a lesser volume of oxygenated pulmonary venous blood. While the right-to-left shunt in such a case with a very large atrial septal defect would be greater than if the defect were small, the shunted blood would be less well saturated with oxygen. It is possible that there is an optimal size for the interatrial communication, and this may explain why some patients die in infancy while others live to adulthood.

Approximately one-half of the cases of total anomalous pulmonary venous drainage present a characteristic appearance on a routine chest roentgenogram.[9-11] The typical mediastinal shadow is formed when total pulmonary drainage occurs via the left innominate vein into the right superior vena cava. The heart and the mediastinal shadow have been described as creating a "figure-of-8"[9] or dumbbell appearance,[10] which may be apparent in early infancy.[14] When all of the pulmonary veins empty into the right atrium directly, or by way of the coronary or portal venous system, the figure-of-8 configuration, of course, will not be present.

Physical examination in cases of total anomalous venous drainage will generally reveal evidence of right ventricular enlargement, a prominent pulmonic second sound, and a moderately loud systolic murmur with maximal intensity between the second and fourth left intercostal spaces parasternally. Occasionally a pulmonic diastolic murmur is present, and in a few cases there has been a venous hum in the pulmonic area.[11] Although there is almost always some oxygen unsaturation of the arterial blood because of the right-to-left shunt, clubbing of the fingers is uncommon, and cyanosis is generally not seen until terminally. Cardiac fluoroscopy will typically demonstrate enlargement of the right atrium and ventricle, prominent pulmonary vasculature, and expansile hilar artery pulsations. If the total anomalous drainage occurs via the left innominate vein, the large ovoid shadow in the superior mediastinum may be seen. The electrocardiogram generally reveals right ventricular hypertrophy or incomplete right bundle branch block.

A definitive diagnosis may be established by actual angiocardiographic visualization of the anomalous venous return and by cardiac catheterization. The oxygen saturation of blood samples obtained from the right atrium, right ventricle, and pulmonary artery will all be similar and essentially the same as that obtained in a peripheral artery. This will rarely occur in other congenital cardiovascular conditions. In the absence of associated anomalies, cases of total anomalous drainage will generally have a moderate pulmonary hypertension, although some cases,[10] like ours, have been reported with normal pressures in the right-sided chambers at rest.

Most cases (approximately 60 per cent) of total anomalous pulmonary venous drainage are not associated with other significant congenital cardiovascular anomalies.[15] Thus it would appear that complete surgical correction could be obtained by anastamosing the anomalous pulmonary veins to the left atrium. Indeed, Gerbode and Hultgren[16] demonstrated the feasibility of anastamosing large veins to the left atrium in the dog, and Kirklin[17] has reported the successful correction of a case of partial anomalous pulmonary venous drainage. Unfortunately, however, in cases of total anomalous pulmonary venous drainage, the left atrium and its appendage are so underdeveloped that it is difficult to achieve an adequate anastamosis with a large pulmonary vein. There have been nine attempts at surgical correction of total anomalous pulmonary venous drainage reported to the present.[4,9,11,18] Six of the patients died postoperatively and in two cases no anastamosis could be performed, although the patients survived the thoracotomy. In one case, Muller[18] was able to create an anastomosis between the side of the left superior pulmonary vein and the left atrium with definite improvement in the patient's condition postoperatively. It is likely that more successful surgical results will be obtained in the future but at the present time, it would appear that surgery should be reserved for the more seriously disabled patients.

SUMMARY

A case of total anomalous pulmonary venous drainage in an adult has been presented with angiocardiograms and cardiac catheterization findings. The clinical picture of this condition is reviewed. Although total anomalous pulmonary venous drainage is potentially completely correctible by surgery, at the present time surgical efforts should probably be reserved for the more seriously disabled patients.

REFERENCES

1. Brody, H.: Drainage of the Pulmonary Veins Into the Right Side of the Heart, Arch. Path. **33**:221, 1942.
2. Dotter, C. T., Hardisty, N. M., and Steinberg, I.: Anomalous Right Pulmonary Vein Entering the Inferior Vena Cava: Two Cases Diagnosed During Life by Angiocardiography and Cardiac Catheterization, Am. J. M. Sc. **218**:31, 1949.
3. Grishman, A., Poppel, M. H., Simpson, A. S., and Sussman, M. L.: The Roentgenographic and Angiocardiographic Aspects of (1) Aberrant Insertion of Pulmonary Veins Associated With Interatrial Septal Defect and (2) Congenital Arteriovenous Aneurysm of the Lung, Am. J. Roentgenol. **62**:500, 1949.
4. Friedlich, A., Bing, R. J., and Blount, S. G., Jr.: Physiological Studies in Congenital Heart Disease. IX. Circulatory Dynamics in the Anomalies of Venous Return to the Heart Including Pulmonary Arteriovenous Fistula, Bull. Johns Hopkins Hosp. **86**:20, 1950.
5. Knutson, J. R. B., Taylor, B. E., Pruitt, R. D., and Dry, T. J.: Anomalous Pulmonary Venous Drainage Diagnosed by Catheterization of the Right Side of the Heart: Report of Three Cases, Proc. Staff Meet., Mayo Clin. **25**:52, 1950.
6. Hwang, W., Prec, O., Kuramoto, K., Segall, S., and Katz, L. N.: Hemodynamic Study of Case of Anomalous Pulmonary Venous Drainage, Circulation **2**:553, 1950.
7. Levinson, D. C., Griffith, G. C., Cosby, R. S., Zinn, W. J., Jacobson, G., Dimitroff, S. P., and Oblath, R. W.: Transposed Pulmonary Veins. A Correlation of Clinical and Cardiac Catheterization Data, Am. J. Med. **15**:143, 1953.
8. Healy, J. E.: An Anatomic Survey of Anomalous Pulmonary Veins: Their Clinical Significance, J. Thoracic Surg. **23**:433, 1952.
9. Snellen, H. A., and Albers, F. H.: The Clinical Diagnosis of Anomalous Pulmonary Venous Drainage, Circulation **6**:801, 1952.

10. Gardner, F., and Oram, S.: Persistent Left Superior Vena Cava Draining the Pulmonary Veins, Brit. Heart J. **15**:305, 1953.
11. Keith, J. D., Rowe, R. D., Vlad, P., and O'Hanley, J. H.: Complete Anomalous Pulmonary Venous Drainage, Am. J. Med. **16**:23, 1954.
12. Edwards, J. E.: Pathologic and Developmental Considerations in Anomalous Pulmonary Venous Connections, Proc. Staff Meet., Mayo Clin. **23**:441, 1953.
13. Edwards, J. E.: Congenital Malformations of the Heart and Great Vessels, In Gould: Pathology of the Heart, 1953, Springfield, Ill., Charles C Thomas.
14. Parsons, H. G., Purdy, A., and Jessup, B.: Anomalies of the Pulmonary Veins and Their Surgical Significance: Report of Three Cases of Total Anomalous Pulmonary Venous Return, Pediatrics **9**:152, 1952.
15. Smith, J. C.: Anomalous Pulmonary Veins, AM. HEART J. **41**:561, 1951.
16. Gerbode, F., and Hultgren, H.: Observations on Experimental Atriovenous Anastamosis, With Particular Reference to Congenital Anomalies of the Venous Return to the Heart, and to Cyanosis, Surgery **28**:235, 1950.
17. Kirklin, J. W.: Surgical Treatment of Anomalous Pulmonary Venous Connection (Partial Anomalous Pulmonary Venous Drainage), Proc. Staff Meet., Mayo Clin. **28**:476, 1953.
18. Muller, W. H., Jr.: The Surgical Treatment of Transposition of Pulmonary Veins, Ann. Surg. **134**:683, 1951.

Review of Recent Advances

THEORY OF VECTORCARDIOGRAPHY: A REVIEW OF FUNDAMENTAL CONCEPTS

ROBERT A. HELM, M.D.*

CINCINNATI, OHIO

A VECTOR is a symbol (an arrow) for expressing the magnitude and the direction of a force. Spatial vectorcardiography is a form of electrocardiography which attempts to depict the electromotive force developed by the heart at each instant of time as a single vector. All of the successive instantaneous vectors are represented as having a common point of origin. The termini of the successive instantaneous vectors are joined by a line, the configuration of which is determined by the variations in the magnitudes and directions of the successive instantaneous vectors.

Such a representation implies at least three important assumptions: (1) The resultant of all of the electromotive forces arising throughout the heart at any instant of the cardiac cycle may be represented by a single vector. (2) The origins of all successive vectors are located at a common point throughout the cardiac cycle. (3) Vector representation of the resultant cardiac electromotive forces may be accurately determined from measurements of potential differences between points located on the body surface. It is the purpose of this review to examine critically the evidence for the validity of these assumptions. In part A several aspects of the subject are approached from a purely physical standpoint. In part B the concepts elucidated in A are extended and modified to apply to the heart and are utilized as a background against which the results of published experimental investigations are evaluated.

Throughout this review an attempt has been made to present certain mathematical concepts in terms of concrete arithmetical illustrations. The use of abstract mathematical symbols has been limited to simple algebraic and vector expressions. It is believed that such an approach will better clarify, for the majority of readers, the basic principles involved.

A. GENERAL PRINCIPLES AND CONCEPTS

The Effect of Dipole Eccentricity on the Potential Differences Recorded by Two Anatomically Parallel Leads of Equal Magnitude.—This can be most simply demonstrated with the aid of Fig. 1. Let A, B, C, and D represent four points on the circumference of a circular homogeneous conducting lamina of unit radius.

From the Cardiac Laboratory, Cincinnati General Hospital and Department of Internal Medicine, College of Medicine, University of Cincinnati, Cincinnati, Ohio.

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*Public Health Service Research Fellow of the National Heart Institute.

The locations of the points are such that the diameters $\overline{AD}$ and $\overline{BC}$ bisect the four quadrants defined by the horizontal and vertical coordinates, x and y. It is then obvious that $\overline{AB}$ and $\overline{CD}$ are parallel and that $\overline{AC}$ is perpendicular to both $\overline{AB}$ and $\overline{CD}$.

Let us next place a dipole* consecutively at four locations on radius $\overline{OD}$ as illustrated. These consecutive dipoles will be designated as *0*, *.1*, *.3*, and *.5*, since each designation refers to the distance of the dipole center from *0* expressed as a coefficient of the radius. At each of the four dipole centers the dipole will be arbitrarily oriented along six angular axes with respect to the x axis (0°, 30°, 60°, 90°, 135°, 180°).

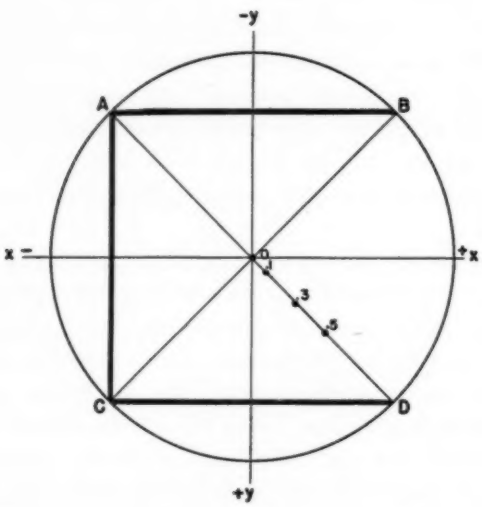

Fig. 1.—The points, *A*, *B*, *C*, and *D*, are located on the circular homogeneous conducting lamina as described in the text. The points, *0*, *.1*, *.3*, and *.5*, represent the consecutive locations of the dipole on the lamina.

The potentials, V_A, V_B, V_C, and V_D at each of the respective points, 1, *B*, *C*, and *D*, may now be calculated and expressed as a coefficient of the moment (i.e., strength) of the dipole for each of its four locations and each of its six axial orientations. These calculations were made (for the eccentric dipoles) by means of Equation (19) (for V_B and V_C), Equation (21) (for V_D) and Equation (22) (for V_A), given in the paper of Wilson and Bayley[2] to which the reader is referred. The calculated potential at each point is listed in Table I as the coefficient of the dipole moment existing at any instant. Since such a moment is constant for each dipole location and each dipole axis, the difference of potential between two points may be determined and expressed as the coefficient of any dipole moment. These values are given in Table I under the headings $V_C - V_A$, $V_B - V_A$, and $V_D - V_C$.

*A dipole (or doublet) may be defined either as a single pair of positive and negative charges in close proximity or as a source-sink pair. Throughout this discussion the concept of a mathematical dipole may be used. This has been defined as a dipole with infinitesimal source-sink separation but with a finite product of source-sink strength times separation.[1]

TABLE I. POTENTIALS AT POINTS A, B, C, D OF FIG. 1

POTENTIAL EXPRESSED AS A COEFFICIENT OF THE DIPOLE MOMENT	LOCATION OF DIPOLE	ORIENTATION OF DIPOLE AXIS					
		0°	30°	60°	90°	135°	180°
V_A	0	−2.13	−2.91	−2.91	−2.13	.00	2.13
	.1	−1.81	−2.48	−2.48	−1.81	.00	1.81
	.3	−1.38	−1.89	−1.89	−1.38	.00	1.38
	.5	−1.10	−1.50	−1.50	−1.10	.00	1.10
V_B	0	2.13	.78	− .78	−2.13	−3.00	−2.13
	.1	1.92	.52	−1.01	−2.28	−2.96	−1.92
	.3	1.45	.06	−1.35	−2.39	−2.72	−1.45
	.5	.99	− .29	−1.50	−2.30	−2.33	− .99
V_C	0	−2.13	− .78	.78	2.13	3.00	2.13
	.1	−2.28	−1.01	.52	1.92	2.96	2.28
	.3	−2.39	−1.35	.06	1.45	2.72	2.39
	.5	−2.30	−1.50	− .29	.99	2.33	2.30
V_D	0	2.13	2.91	2.91	2.13	.00	−2.13
	.1	2.53	3.46	3.46	2.53	.00	−2.53
	.3	3.90	5.32	5.32	3.90	.00	−3.90
	.5	7.07	9.66	9.66	7.07	.00	−7.07
V_C-V_A	0	.00	2.13	3.69	4.26	3.00	.00
	.1	− .47	1.47	3.00	3.73	2.96	.47
	.3	−1.01	.54	1.95	2.83	2.72	1.01
	.5	−1.20	.00	1.21	2.09	2.33	1.20
V_B-V_A	0	4.26	3.69	2.13	.00	−3.00	−4.26
	.1	3.73	3.00	1.47	− .47	−2.96	−3.73
	.3	2.83	1.95	.54	−1.01	−2.72	−2.83
	.5	2.09	1.21	.00	−1.20	−2.33	−2.09
V_D-V_C	0	4.26	3.69	2.13	.00	−3.00	−4.25
	.1	4.81	4.47	2.94	.61	−2.96	−4.81
	.3	6.29	6.67	5.26	2.45	−2.72	−6.29
	.5	9.37	11.16	9.95	6.08	−2.33	−9.37
$Q(1-q)(V_B-V_A)$ + $Qq(V_C-V_A)$	0	4.26	3.69	2.13	.00	−3.00	−4.26
	.1	4.81	4.47	2.93	.61	−2.96	−4.81
	.3	6.29	6.67	5.26	2.45	−2.72	−6.29
	.5	9.37	11.17	9.96	6.08	−2.33	−9.37

The potentials at points *A*, *B*, *C*, and *D*, of Fig 1. are expressed as coefficients of the dipole moment for each of the four dipole locations (.5, .3, .1, and 0) and each of the six axial orientations between 0° and 180°. The potential differences between points are also expressed as coefficients of the dipole moment. See text.

The potential differences, V_B - V_A and V_D - V_C, might be expected to be identical for any given dipole location and dipole axis, since they are recorded by anatomically parallel leads of identical length. Reference to Table I, however, shows that this does not obtain except for (1) the centric dipole and (2) the eccentric dipoles when the dipole axis is at 135°, that is perpendicular to the diameter $\overline{AD}$ upon which the dipole centers are located. The latter represents a special case which would not exist if the dipole were located at any position on the circular lamina except on the diameters $\overline{AD}$ and $\overline{BC}$.

Therefore, it may be concluded that the projection of a dipole upon anatomically parallel leads of equal length will not produce equivalent deflections if the dipole is eccentric. Furthermore, as demonstrated by inspection of Table I, the discrepancy between the deflections increases, apparently geometrically, with increasing dipole eccentricity.

2. *Reorientation of Lead Directions and Magnitudes as a Means of Correcting for Dipole Eccentricity.*—It is with this aspect of electrocardiographic leads that the concept first described by Burger and Van Milaan[3] finds useful application. These authors demonstrated that the scalar deflection in an electrocardiographic lead is equivalent to the product of two vectors, one of which is the lead itself (the so-called "lead vector") and the other of which is the electromotive force producing the deflection. In order to clarify this concept, it will be illustrated in some detail with the data calculated previously for a single plane.

If $V_B - V_A$ and $V_D - V_C$ are horizontal leads, as they appear to be anatomically, a vertically oriented dipole axis (90°) would be expected to produce zero deflection in each of these leads. Inspection of Table I indicates that this expectation is not realized for any of the dipole positions except the centric one. This suggests then that the effective lead axes* of $V_B - V_A$ and of $V_D - V_C$ may be oriented in directions other than horizontal. The effective lead axis may be found by relocation of the points, *A*, *B*, *C*, and *D*, depending upon their respective potentials. Let us consider any of the eccentric dipoles, with an assumed moment of unity, the axis of which is oriented first horizontally (0°) and then vertically (90°). For these two dipole orientations, the respective potentials at *A*, *B*, *C*, and *D* may be obtained from Table I.

Let us now plot these paired (horizontal and vertical) potentials to relocate points *A*, *B*, *C*, and *D* with respect to the *x* and *y* coordinate axes for each eccentric dipole. Lines drawn between the relocated points now represent the reoriented lead axes which are illustrated in Fig. 2. It can be readily seen that each effective lead axis is the hypotenuse of a right triangle, the other two sides of which are equivalent to the differences in potential recorded by the lead when the axis of a dipole of unit moment is oriented horizontally and vertically, respectively. The dipole is now located at the center, 0′, of the *xy* coordinate frame. The axes and magnitudes of the leads have been reoriented on this frame to correct for the eccentricity of the dipole center on the circular lamina. By means of such a diagrammatic reorientation, a lead takes on the properties of a vector quantity. The deflection in a given lead produced by a dipole with fixed location but with variable axis is equal to the product of the projection of the dipole vector upon the effective lead axis and the magnitude of this effective lead. Written as a simple equation in vector terms, similar in form to that given by Burger and Van Milaan,[3] this relationship is

$$V = \vec{e}\,\vec{l} = \bar{e}\,\bar{l}\cos\theta \qquad (1)$$

where V is the lead deflection, $\vec{e}$ is the dipole vector, $\vec{l}$ is the lead vector, $\bar{e}$ and $\bar{l}$ are the respective vector magnitudes, and θ is the angle between the dipole axis

*Schaffer and his associates[4] have introduced the excellent term, "effective lead axis," to indicate that a lead has been reoriented geometrically to correct for dipole eccentricity.

and the lead axis. The reader can verify this relationship by utilizing the numerical data given for each eccentric dipole in Fig. 2 and comparing the results with the corresponding coefficients of the dipole moment given in Table I.

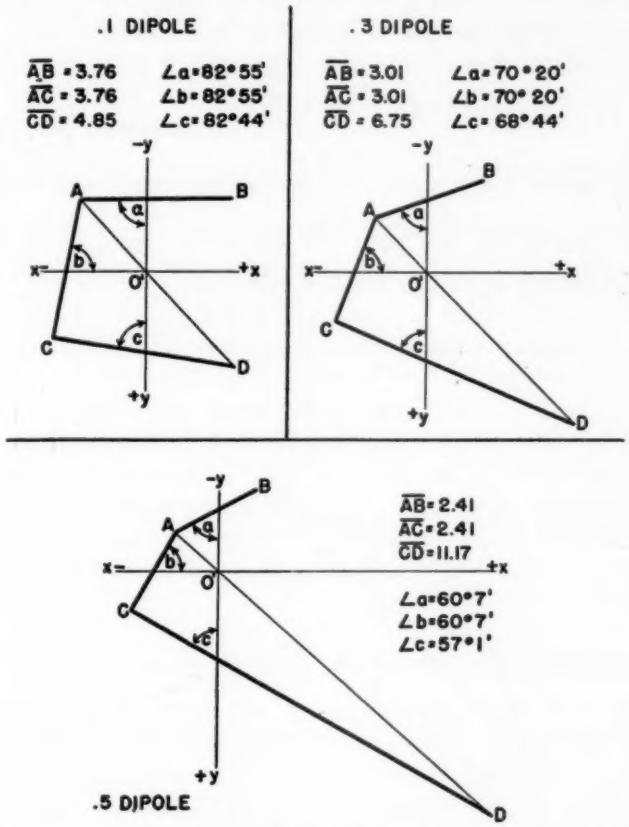

Fig. 2.—Diagrams representing the reorientations of the leads, $V_B - V_A$, $V_C - V_A$, and $V_D - V_C$, for each of the eccentric dipole locations are constructed in accordance with the concept of lead vectors. The magnitudes and directions of each of the lead vectors are given. (See text.)

For a spatial coordinate frame the effective lead is the hypotenuse of the rectilinear trihedron formed by the projections of a unit dipole upon the three coordinate axes x, and y, and z when the dipole axis is consecutively oriented in a horizontal, vertical, and sagittal direction. The equation for calculating the scalar deflection of a lead in a spatial reference frame arranged about an eccentric dipole is also Equation (1) which may be alternately expressed in terms of the x, y, and z scalar components of the two vectors as

$$V = \vec{e}\,\vec{l} = e_x l_x + e_y l_y + e_z l_z \ .$$

Thus the application of Burger and Van Milaan's concept is not limited to a single plane.

The fact that a different reorientation of the effective magnitude and direction of an anatomic lead must occur with each change in location of the dipole center, as graphically demonstrated in Fig. 2, is of considerable practical importance in the application of the dipole theory to vectorcardiography.

3. *Duplication of the Scalar Deflection Recorded in a Given Lead by the Algebraic Addition of the Scalar Deflections Obtained in Other Differently Oriented Leads.*—For the sake of simplicity the data previously calculated and recorded in Table I will again be utilized for illustrative purposes. The diagram of the reoriented effective leads for the .3 dipole is reproduced in Fig. 3. From the constructions and derivations given in the appendix it is shown that

$$\vec{CD} = \vec{AE} = Q\,(1-q)\,(\vec{AB}) + Qq\,(\vec{AC}) \qquad (2)$$

where $Q = \frac{\overline{AE}}{\overline{AE'}}$ and q is any quantity varying between 0 and 1 depending on the dipole location. Since $\vec{AB}$, $\vec{AC}$, and $\vec{CD}$ are known for each dipole center, and $\vec{AE'}$ may be calculated trigonometrically, the quantities Q and q can be determined. The latter are given for each dipole location in Table II. These are substituted in the equation heading the last column of Table I. It is obvious

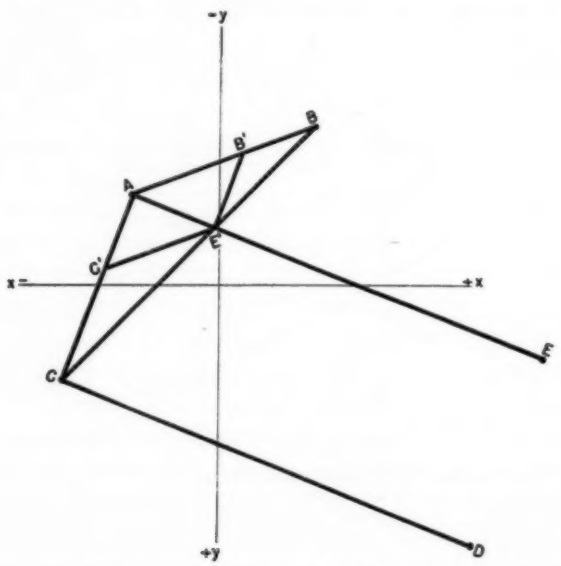

Fig. 3.—Geometric construction, superimposed on the reoriented lead vectors for the .3 dipole, from which the coefficients, Q and q, are calculated from Equation (2), derived in Appendix I. $\overline{B'E'}$, $\overline{C'E'}$, and $\overline{AE}$ are parallel to $\overline{AC}$, $\overline{AB}$, and $\overline{CD}$, respectively. $\overline{AE}$ and $\overline{CD}$ are of equal magnitude.

TABLE II. COEFFICIENTS, Q AND q, CALCULATED AS DESCRIBED IN THE TEXT AND SUBSTITUTED IN THE FORMULA HEADING THE LAST COLUMN OF TABLE I

	DIPOLE LOCATION			
	.5	.3	.1	0
Q	17.403	4.802	1.659	1.000
q	.471	.396	.199	.000
Q (1-q)	9.2016	2.9010	1.3294	1.0000
Qq	8.2016	1.9010	.3294	.0000

from examination of this column that the deflections recorded in Leads V_B - V_A and V_C - V_A may be modified by suitable coefficients and added algebraically to yield the same deflections recorded in Lead V_D - V_C. This holds true for any orientation of the dipole axis; the coefficients are constant for a single dipole location but will vary if the dipole center migrates to another location.

By means of the equation,

$$\text{Lead x} = Q\,(1 - q_1 - q_2 \ldots q_n)\,\text{Lead 1} + Qq_1\,\text{Lead 2} + Qq_2\,\text{Lead 3} + \ldots Qq_{n-1}\,\text{Lead n} \tag{3}$$

derived in a previous paper,[5] any number of scalar lead deflections may be added to yield a scalar deflection equivalent to that obtained with a lead of any magnitude and direction. Thus the principle discussed in this section applies to spatial leads as well as to those limited to a single plane.

4. *Principles Underlying the Summation of Multiple Instantaneous Dipoles.*—If multiple dipoles are placed simultaneously on the circular lamina illustrated in Fig. 1, the potential developed at any given point represents the algebraic addition of the potentials which would be produced at this point by each dipole acting independently. Thus for points, 1, 2, . . .n, at which dipole forces, e_1, e_2, . . .e_n arise, the lead deflection, V, produced by all of these forces may be expressed as a summation of the terms of Equation (1),

$$V = \vec{e_1}\vec{l_1} + \vec{e_2}\vec{l_2} + \ldots\vec{e_n}\vec{l_n} \tag{4}$$

where $\vec{l_1}$, $\vec{l_2}$, . . .l_n represent the lead vectors for each individual dipole center at which electromotive forces $\vec{e_1}$, e_2, . . .e_n arise. This is in accordance with the "Principle of Superposition" which is discussed more fully by Wilson and Bayley[2] and, interestingly enough, was discovered by them to have been first stated and proved by Helmholz in an article, published in 1853, on the distribution of electric currents in volume conductors. This principle, however, does not permit the assumption, stated or implied in several texts on vectorcardiography,[6,7] that multiple dipoles may be represented at each instant by a single resultant dipole. The latter is a legitimate representation of two or more dipoles located at the same point but not at different points. This may be clarified by a simple example. Let us assume the existence of two dipoles, each of unit moment, located at point 0 in Fig. 1. Let each dipole axis coincide with diameter *AD* but let the positive pole of the one point toward *D* and the positive pole of the other point toward *A*. The potentials developed at points *A*, *B*, *C*, and *D* would then of course be zero in each instance. Without varying the moment or the axial orientation of either dipole, let the center of the one whose positive pole faces *D* be located at point .1 on radius *OD* and let the center of the other whose positive pole faces *A* be located at the corresponding point on radius *OA*. With the aid of Table I we now find that the potentials developed at *A*, *B*, *C*, and *D* are (3.58) + (−2.56) = 1.02, (−.25) + (−.25) = −.50, (−.25) + (−.25) = −.50, and (3.58) + (−2.56) = 1.02, respectively. It is manifestly impossible for any single resultant dipole, regardless of its moment, position, or orientation, to produce a positive potential of 1.02 at the two diametrically opposite points, *A* and *D*.

It is, therefore, obvious that the concept of a single resultant dipole is applicable to multiple dipoles only if they are located at a single point, or, less rigidly but of more practical importance, if they form a cluster, the diameter of which is very small when compared with the distance from its center to the closest electrode of a lead. Burger and van Milaan were cognizant of this fact and stated it explicitly in a discussion of precordial leads in their third paper.[3] Nevertheless it limits the validity of applying their measurements (or those subsequently developed by others)[8,9] to electrocardiographic leads, since the heart is relatively large in proportion to the size of the body. Other approaches to this problem will be discussed later in the section dealing with precordial leads.

5. *The Algebraic Addition of Scalar Lead Deflections Produced by Multiple Dipoles.*—In Section 3, it was demonstrated that for any single dipole located at a fixed point on the circular lamina,

$$V_D - V_C = Q\,(1-q)\,(V_B - V_A) + Qq\,(V_C - V_A) \tag{5}$$

and that the quantities Q and q were constants for that dipole regardless of its moment or its axial orientation. In Section 4, it was pointed out in a nonmathematical manner that, if the subscripts 1, 2, . . .n are used in the expressions pertaining to the individual potentials produced by each of n dipoles and the subscript T is used for the expression pertaining to the total potential produced by n dipoles, the following equations must be true.

$$\begin{aligned} V_{DT} - V_{CT} &= (V_{D1} - V_{C1}) + (V_{D2} - V_{C2}) + \ldots (V_{Dn} - V_{Cn}) \\ V_{BT} - V_{AT} &= (V_{B1} - V_{A1}) + (V_{B2} - V_{A2}) + \ldots (V_{Bn} - V_{An}) \\ V_{CT} - V_{AT} &= (V_{C1} - V_{A1}) + (V_{C2} - V_{A2}) + \ldots (V_{Cn} - V_{An}) \end{aligned} \tag{6}$$

By using the same subscripts to designate conveniently the quantities Q and q for their respective dipoles, the principles elucidated in Sections 3 and 4 may be combined by means of Equation (7), the individual V terms on the right hand side being dependent upon Equation (4).

$$\begin{aligned} V_{DT} - V_{CT} = {} & Q_1\,(1-q_1)\,(V_{B1} - V_{A1}) + Q_1q_1(V_{C1} - V_{A1}) + \\ & Q_2\,(1-q_2)\,(V_{B2} - V_{A2}) + Q_2q_2(V_{C2} - V_{A2}) + \ldots \\ & Q_n\,(1-q_n)\,(V_{Bn} - V_{An}) + Q_nq_n(V_{Cn} - V_{An}) \end{aligned} \tag{7}$$

However, Equation (7) cannot be reduced to the simpler form,

$$V_{DT} - V_{CT} = Q_T\,(1-q_T)\,(V_{BT} - V_{AT}) + Q_Tq_T\,(V_{CT} - V_{AT}) \tag{8}$$

unless all of the n dipoles have the same moment and the same axial orientation at the instant of recording their summation potentials. The reader may prove this point with an arithmetical example. It may be calculated from the data given in Table I that the total potentials at points *A*, *B*, *C*, and *D* are −6.42, 6.49, −9.10 and 15.63, respectively, for four horizontal dipoles, each of unit moment, acting simultaneously at locations .5, .3, .1, and 0. The corresponding total potentials at points *A*, *B*, *C*, and *D* are −6.42, −9.10, 6.49, and 15.63, respectively, when all four unit dipoles are oriented vertically. By utilizing these data in simultaneous equations of the form of Equation (5), the coefficients, Q (1-q) and Qq, are calculated to be 2.155 and 1.155, respectively. It may then be shown arithmetically with the aid of Table I that these coefficients are valid not only when the four dipoles, located at .5, .3, .1, and 0, are oriented horizontally

and vertically but also when they are oriented along any axis, provided that all four dipoles simultaneously have the same axial orientation and the same moment. The fact that the principle discussed in Section 3 does not hold for the summation potentials of multiple dipoles with unequal moments or different axial orientations limits its application in vectorcardiography.

B. APPLICATION OF THEORECTIC PRINCIPLES TO THE RECORDING OF ELECTROMOTIVE FORCES PRODUCED BY THE HEART

Thus far the discussion has been limited entirely to physical rather than to biologic considerations. Let us now examine in detail some of the problems involved in applying these physical concepts to the recording of the electromotive forces produced by the heart.

1. *The Problems Imposed by Nonhomogeneity of the Conducting Medium and Irregularity of Its Limiting Boundary.*—If the reader examines the equations given in the paper of Wilson and Bayley,[2] he will find that, while Equation (11) for representing the potential produced by a centric dipole in an infinite medium is relatively simple, Equation (17) for an eccentric dipole in an infinite medium, and Equation (18) for an eccentric dipole in a limited but spherical medium, become progressively more complex. All of these equations have been derived with the assumption of a homogeneous medium. They are, therefore, not applicable to a volume conductor containing tissues which are not electrically homogeneous, since inhomogeneity must affect the distribution of dipole current. A limiting boundary formed by a nonelectrolyte (i.e., air) surrounding the volume conductor also affects the distribution of dipole current within the latter. If the limiting boundary of the body had some definable geometric configuration, it might be possible to derive a suitable expression, similar to but more complex than Wilson and Bayley's Equation (18) for a spherical homogeneous medium. The irregularity of the surface of the trunk, however, does not permit it to be represented accurately as a circular or an elliptical cylinder or to be defined by any precise mathematical expression. It will be shown in this section that, despite these seemingly insurmountable difficulties, the factors of tissue inhomogeneity and limiting boundary irregularity, like that of dipole eccentricity, can be obviated when the concept of a lead vector is utilized.

Wilson and Bayley's Equation (18) for an eccentric dipole in a homogeneous spherical conducting medium may be expressed, when stripped to its bare essentials, as

$$V_p = M_x K_x + M_y K_y + M_z K_z \qquad (9)$$

where V is the potential at any point p, M is the moment of the dipole, subscripts $_x$, $_y$, and $_z$ are the direction cosines of the axis of the dipole with respect to the x, y, and z coordinate axes, and K_x, K_y, and K_z are constants depending upon the location of the dipole, the location of the point p, and in the case of a spherical medium, its radius. However, for a medium which is neither spherical nor homogeneous, but which possesses properties that, while quantitatively undefinable, are nevertheless fixed, the constants, K_x, K_y, and K_z can be considered

to be determined in part by these additional unknown factors. Therefore, Equation (9) may be applied to any fixed medium and is in fact an expression of a further aspect of Helmholz's "Principle of Superposition" as discussed by Wilson and Bayley[2] and by Frank.[10] This equation is applicable when the body acts as a volume conductor if the variation in its conductivity resulting from respiration[3,11] and blood flow[12] is neglected. Experimental investigations utilizing both homogeneous and inhomogeneous two-dimensional[13] and three-dimensional[3,9] models, human cadavers[8] and living human subjects[15] amply confirm the theoretical applicability of Equation (9). Lead vectors can and, in fact, have been defined for multiple points on the surface of a model or cadaver in which a dipole is placed in a location corresponding to the center of the heart.[3,8,9,13,14] In the case of living subjects an artificial dipole has been placed on the chest surface for the same purpose.[15] It has been suggested[16] that small, slightly separated electrodes could be placed within the right ventricle of the living subject by means of a catheter, the positions of these electrodes determined roentgenographically, and current passed through the body between any two points representing a lead under study. By the Principle of Reciprocity,[2,16] the potential measured between the electrodes in the right ventricle would be identical with that which would be measured by the body surface lead, were an identical current to be passed between the intraventricular electrodes; the latter would be a somewhat hazardous procedure, whereas the method based upon the reciprocity theorem would involve only the risk involved in right ventricular catheterization. It is fair to predict that, with an increasing number of investigators turning their attention to the concept of Burger and van Milaan,[3] the time is not far distant when coefficients, defining lead vectors for numerous dipole positions within the heart and for widely varying body configurations, will become available. From the form of Equation (9) it is readily apparent that it is identical with Equation (1), M_x, M_y, and M_z representing the scalar components of $\vec{e}$, and the experimentally determined K_x, K_y, and K_z representing the scalar components of $\vec{1}$. If multiple dipole positions within the heart are investigated, the experimental data for substitution in Equation (4) becomes available, the applications of which will be discussed in the next section and in Part II of the appendix.

2. *The Problems Imposed by the Finite Size of the Heart.*—The precise mechanism by which electromotive forces are produced by the heart is not well understood. Various theories involving slightly different mechanisms have been proposed. These have been reviewed and lucidly discussed in Craib's paper,[17] to which the reader is referred. For the present discussion the actual mechanism of the production of the electromotive forces is of little import; it is sufficient to note that such forces are developed at multiple areas within the heart. For convenience we shall consider that, at a given instant, a dipole develops at each point in the myocardium where electrical activation takes place. Since such a dipole must have a certain moment and a certain axial orientation, it could be represented graphically as a vector quantity. However, the only quantities available for instrumental recording are the differences in potential between any points on or within the body developed from the resultant of all of the individual dipoles existing at each instant. It is a fundamental

tenet of vectorcardiography that this resultant of the electromotives forces of the heart can be represented as a single vector. The principle governing the summation of dipole forces has been stated in Section 4 of part A. It is obvious that all of the individual dipoles developed at each instant within the heart are not located at a single point which is the requisite for absolute mathematical accuracy. Are they located, however, in a sufficiently small cluster that they may, for practical purposes, be considered to be located at a single point? A second equally important question is: If a single resultant dipole is assumed at each instant, is it located, again for practical purposes, at approximately the same point during successive instants of the cardiac cycle? The interplay between these two basic questions will become more apparent from a consideration of the experimental methods utilized to answer them. The influence of the finite size of the heart on precordial leads and on distant leads will be considered separately and in some detail, since the questions concerned involve the foundation upon which vectorcardiography has been developed.

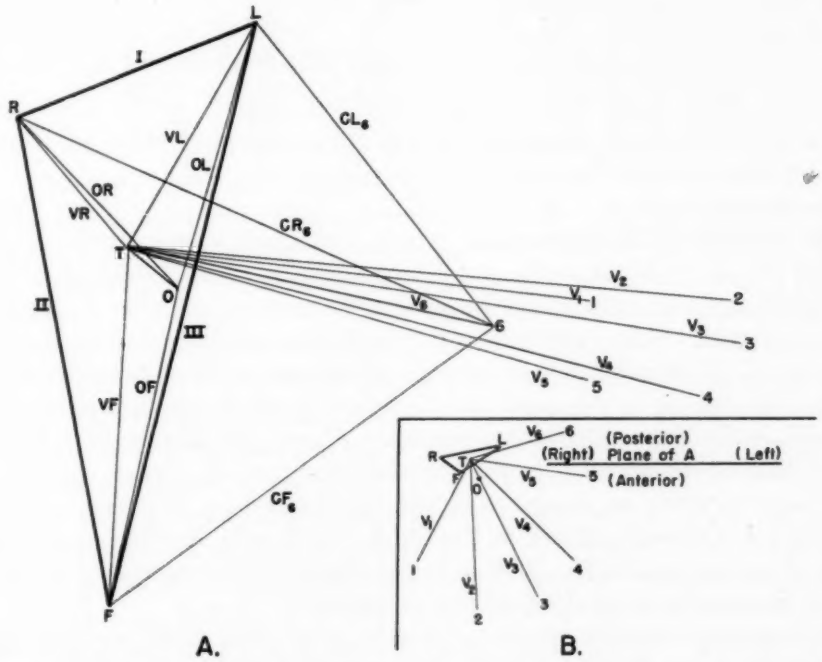

Fig. 4.—Diagram *A* represents the lead vectors of the standard leads, "unipolar" extremity leads, and "unipolar" precordial leads, constructed from the data published by Frank.[9] In order to demonstrate their magnitudes and angles of declination, the precordial lead vectors, V_1 to V_6 and CR_6, CL_6, and CF_6 are displayed as if they were located on the frontal plane. The true spatial positions of vectors V_1 to V_6 are depicted in *B*, representing the transverse plane, drawn to a scale of 1:4 with reference to *A*. See text.

a. Precordial leads: Fig. 4, *A* is a diagrammatic representation, similar to that published by Selvini and associates,[18] of the application of the vector concept to precordial leads. The triangle *RLF* represents an oblique triangle

constructed from the coefficients obtained by Burger and van Milaan[3] from experimental measurements of the differences in potential between the extremities (*R*, *L*, and *F*) of their model when a dipole, consecutively oriented horizontally and vertically, was located in a position corresponding to that of the heart. The coefficients subsequently obtained by den Boer[8] and by Frank[9] are quite similar. The point, *T*, representing the Wilson central terminal, is located at the intersection of the medians of the triangle, since such a geometric representation depicts precisely the electrical formation of the terminal.

Point *O*, representing the dipole center or alleged "electrical center" of the heart, although necessarily appearing to lie on the plane of *RLF*, is actually located anterior to this triangle as well as inferiorly and to the (patient's) left of *T*. This location, not ascertainable from the work of Burger and van Milaan,[3] has been derived from the studies of Frank[9] whose unipolar measurements on three-dimensional models were made against a true zero reference potential.[1] It is, therefore, evident that points *T* and *O* do not coincide despite the fact that recent elaborate immersion studies,[19,20] confirming older simpler investigations,[21] suggest that, in the living human subject, the potential of the Wilson central terminal does not deviate greatly from zero. However, the most definite conclusions which can be drawn from immersion experiments[22] are that the magnitude of $\vec{OT}$ (lead vector between the "electrical center" of the heart and the Wilson central terminal) invariably is less than the magnitudes of either $\vec{OR}$, $\vec{OL}$, or $\vec{OF}$ (lead vectors between the "electrical center" of the heart and each of the three extremities).

The locations of the precordial points, *1* through *6*, were determined from the diagrams of the image surface of a homogeneous torso, published by Frank.[9] Lines joining these points with *T* represent the vectors of Leads V_1 through V_6. The *CR*, *CL*, and *CF* lead vectors for the sixth precordial position are also shown. In Fig. 4, *A* all precordial lead vectors, of necessity, have been drawn in the frontal plane (plane of the page) to depict their relative magnitudes and their angles of declination with the horizontal. The reader should be cognizant of the fact that these precordial lead vectors form varying angles with the plane of the page; in order to demonstrate this more clearly a transverse plane view, drawn to a 1:4 scale, is shown in Fig. 4, *B*. It should also be noted in passing that, as demonstrated in Fig. 4, *B*, *R* is anterior to *L*, *F* is anterior to both *R* and *L*, and *O* is anterior to all three extremity points.

If the vector concept can be applied to precordial leads, a single resultant dipole would be projected on both the precordial lead axes as well as the extremity lead axes according to the cosine relationship given in Equation (1). If the precordial point is located approximately on the plane of triangle *RLF*, as is usually the case for the fifth or sixth precordial positions, the lead axes illustrated in Fig. 4, *A* suggest that $CF_{5\text{-}6}$ should resemble in form Lead I, $CL_{5\text{-}6}$ should resemble in form an inverted Lead VR, and $CR_{5\text{-}6}$ and $V_{5\text{-}6}$ should have a configuration varying between that of Lead I and inverted Lead VR. Reference by the reader to published comparisons[23] of standard leads, "unipolar" limb leads, and precordial leads taken with various indifferent electrode points, will suggest that in general such predictions seem to be reasonably valid.

The studies of Grant and Estes[7,24] and of Langner and his associates[25] on unipolar leads recorded as a mosaic over the entire thorax and the work of Simonson on circumferential chest leads[26] suggest that in general the distribution of transitional QRS and T patterns follows pathways which lie on planes perpendicular to the mean spatial QRS and T vectors, respectively. The studies of Langner and Atkins on intrabronchial leads[27] suggest that the transitional patterns of leads recorded within the chest also fall approximately on a plane perpendicular to the mean spatial vector. All of these findings support the single resultant vector concept grossly but do not define its validity precisely.

The studies of Schaefer and his colleagues[28-30] have been directed toward a more precise consideration of precordial leads in terms of vector principles. Their general technique consisted of recording a large number of Wilson unipolar V leads from points around the circumference of the chest. The anatomic points were located on a drawing of a cross section through the chest, and on determining the two points showing the maximally positive or negative QRS voltages and the two points of minimal QRS potential (transitional patterns), the null point or "electrical center" of the heart was determined in two different ways using simple geometric constructions. In most instances the points so located were not greately divergent from each other. After determining the null point, its relative anatomic distance from each of the precordial lead points was measured and the inverse of the square of each of these distances was used to correct the voltage of the mean deflection (measured in millivolt seconds) of each of the respective precordial leads for proximity. The corrected voltages were then represented as vectors arising at the null point and passing through each of the precordial points. If each of these vectors represented the projection on the respective precordial lead axis of a single dipole located at the null point, perpendiculars drawn from the terminus of each should theoretically intersect at a point. The size of the "circle of error" containing the many actually different points of intersection of the perpendiculars thus becomes a measure of the error involved in the assumptions. These authors made such constructions both with different combinations of precordial leads and also with varying locations of the null point. In any given patient the locations of the centers of the "circles of error" for such different constructions did not vary greatly. Schaefer and his co-workers, therefore, concluded that it was possible to construct a mean vector from precordial leads "whose axis and magnitude were hardly influenced by changes in the position of the null point and which remain practically unchanged if the number of the exploring electrodes is varied." In the reviewer's opinion, however, the relatively huge diameters of the "circles of error" cast considerable doubt upon the validity of constructing vectors by such methods from voltages measured in precordial leads. The use of anatomic rather than effective lead axes in such constructions presupposes a large source of error, and it would be of interest if similar studies were repeated with the aid of the recently published torso maps of Frank,[9] a project in progress in this laboratory.

Schmitt and his co-workers have studied the validity of applying the vector concept to precordial leads by means of the technique of cancellation of electrocardiographic mirror patterns.[31-33] The theoretical background for their method

is based upon the following consideration: if V_{P1} and V_{P2} represent the potentials at any two points, P_1 and P_2, located on a straight line passing through a single dipole existing at any fixed location within a spherical homogeneous conducting medium, it may be demonstrated by means of Equation (18) of Wilson and Bayley[2] that $V_{P1} = k\ V_{P2}$ where k is a constant for the points in question, regardless of the moment or axial orientation of the dipole.* When the two points are on opposite sides of the dipole, V_{P1} and V_{P2} are of opposite sign and k becomes a negative quantity. From considerations similar to those discussed in Section 1 of Part B, this concept can be extended to apply to a nonhomogeneous and irregularly bounded medium by postulating that the two points and the dipole need not be located on an anatomically straight line. In living subjects it is impossible to measure the potentials, V_{P1} and V_{P2}, except that they be recorded against the potential of another point or network of points such as the Wilson terminal, designated hereafter as V_T. If two points on the body surface, P_1 and P_2, can be found so that the scalar configurations recorded by the "unipolar" lead, $(V_{P1} - V_T)$ is completely canceled by the addition of the simultaneously recorded scalar configuration of the "unipolar" lead, $(V_{P2} - V_T)$, when the latter is amplified or attenuated by any coefficient, k, constant throughout the period of recording, the following conclusions could be drawn for all instants of the cardiac cycle: (1) The heart is functioning as a single resultant dipole with respect to the points, P_1 and P_2. (2) The location of the resultant dipole is fixed. (3) The potential of the Wilson central terminal is zero if k has any value other than unity. Any other conclusions would not be justified, since the possible occurrence of mutually compensatory variations of these factors during every instant of the cardiac cycle would be beyond the realm of chance. If perfect cancellation is not obtained, however, it is possible neither to determine with finality which of the three factors deviates most markedly from the ideal situation nor to ascertain the compensatory mechanisms involved. Thus the method which utilizes cancellation of mirror patterns involves the factor of a possible finite potential of the "indifferent" reference terminal which could introduce considerable error if either V_{P1} or V_{P2}, or both, are relatively small.

The cancellation technique utilized by Schmitt and his co-workers emphasizes only the maximum scalar discrepancy existing between the mirror patterns at one instant of the QRS interval. It does not always demonstrate small but perhaps diagnostically significant variation between the two mirror patterns which would become evident if the latter were not subjected to cancellation but rather were recorded and compared separately as scalar electrocardiographic patterns. The cancellation technique does, however, differentiate between "true" and "false" mirror patterns,[31] which comparison of scalar tracings does not, unless the latter are recorded simultaneously on the same time scale and compared point for point. Moreover, the cancellation technique permits the experimental data to be expressed quantitatively and to be subjected to statistical analysis.

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*Space will not be utilized for mathematical proof of this fact. It can be demonstrated arithmetically for V_A and V_D in Table I for the limited condition where the line, AD, passes through the center of the circular lamina as well as through each of the dipole centers (Fig. 1).

Schmitt and his associates found that normal individuals provided the best evidence to support the concept of a single resultant dipole representation of the heart since only 9 per cent of any pair of mirror patterns failed to cancel satisfactorily.[32] They were unable to demonstrate that different points on the body or different anatomic distances of electrodes from the heart consistently influenced cancellation quality.[32,33] They further demonstrated that patients with either anterior or posterior myocardial infarctions yielded cancellations which, on the average, were practically identical with, and not significantly inferior to, those of the normal group.[33] They concluded from this finding that localized myocardial lesions do not produce "local patterns" which might be expected to strain most severely the concept of a single resultant dipole. In patients with electrocardiographic evidence of either left or right ventricular hypertrophy, the cancellations tended to be either excellent or inferior.[33] The authors' explanation of the latter group as being due to technical limitations might be questioned since, in general, one would expect the dipole theory to hold less strictly for larger hearts, although the latter explanation would not adequately account for the peculiar distribution obtained. They found significantly poorer cancellations in patients with bundle branch block and attributed this to a mobile dipole,[33] an explanation with which the reviewer is in agreement and which will be discussed more completely later.

Numerous investigators have attempted to evaluate the validity of the application of the single resultant dipole concept to precordial leads by derivation of the latter from a planar vectorcardiogram[6,34-38] or from a spatial vectorcardiogram.[5,39,40] All such studies are based ultimately on the fact that if the effective axis of the actual precordial lead is parallel in space with the axis of the effective lead derived from the vectorcardiogram, the form of the configurations obtained with each lead should be similar except for differences in amplitude. If, in addition to being parallel, the effective lead axes of the precordial and the derived leads have the same magnitudes, their configurations should be identical if the dipole theory is perfectly valid.

Vectorcardiographic derivations of scalar leads have been constructed manually[6,34-38,40] or have been obtained electrically.[5,39] The manual construction is performed by drawing a line through the point of origin of a planar vector loop along any desired axis. Then for each point on the vector loop, corresponding to the terminus of successive instantaneous vectors, a similar point is located on the line of derivation in accordance with the principle of the projection of a vector on a lead [Equation (1)]. When the positions of these points on the line of derivation are plotted on an ordinate and their times of occurrence on an abscissa, a scalar electrocardiographic pattern is obtained. In order to derive a scalar lead from a spatial vectorcardiogram, a planar projection of the latter must first be constructed in such a manner that the desired axis of scalar derivation can be superimposed upon it. The planar projection may be obtained according to the method of Duchosal and Sulzer.[40] A wire model of the spatial vectorcardiogram is constructed, and this can be so oriented in the path of parallel light rays that the shadow of the projection of the vectorcardiogram is cast on any desired plane. The latter may be traced or photographed; the remainder

of the technique is that of constructing a scalar derivation from a planar vectorcardiogram as already described.

Methods of deriving scalar configurations electrically from planar and spatial vectorcardiograms have been described in detail elsewhere.[5,39] The general method depends essentially upon the principle discussed in Section 3 of Part A which can be represented by Equation (3) where lead x is the derived lead. Leads I and II or I, II, and III, representing, respectively, the components of the planar or spatial vectorcardiogram, are amplified and the outputs added by their simultaneous application to a cathode-ray oscilloscope or other suitable galvanometer. The amplification coefficients, q_1 and q_2, determine the direction of the effective axis of the derived lead. The coefficient, Q, determines the amplification or attenuation of the derived lead necessary to adjust the amplitude of its effective vector to be equal to that of the actual precordial lead with which it is being compared. In practice, it is usually simpler to attenuate or amplify the latter by the reciprocal of Q.

The comparison of an actual precordial lead with a planar vectorcardiographic derivation has insurmountable limitations because the lead vector of the former must be parallel to the plane determined by the two component lead vectors of the planar vectorcardiogram. Even if precordial leads are recorded in locations which lie along an anatomically horizontal line[34] rather than in the somewhat staggered positions of V_1 through V_6, the varying magnitudes of the lead vectors make for varying angles of declination. By assuming that the anatomic position of point T could be ascertained, it would be impossible to locate the lead vectors of multiple precordial leads on a single plane because of the unknown manner in which tissue inhomogeneity and limiting boundary irregularity affect the directions of such vectors. Finally, it is impossible to determine the electrical position of the vectorcardiographic plane from inspection of the anatomic location of the component leads.

A derivation obtained electrically from the three component leads of a spatial vectorcardiogram obviates all of these difficulties. The coefficients (Equation 3) can be adjusted to yield the best possible resemblance between the actual and the derived lead with only a general knowledge of the directions of the three vectorcardiographic component lead vectors and the precordial lead vectors.[5] To attempt to adjust the lead axis of a derived lead to be parallel with the alleged direction of the precordial lead axes, estimated from anatomic considerations, is not a valid procedure if one's objective is to test the validity of the dipole hypothesis. The derivation of such a lead manually from a wire model of a spatial loop,[40] as described previously, is likewise unsatisfactory since a plane of projection, estimated to be parallel with the axis of the precordial lead vector, must first be chosen. Moreover, all such manual methods of derivation are much more difficult, time-consuming, and inaccurate than the electrical method.

When comparing a precordial lead with a lead derived from a spatial vectorcardiogram along an axis parallel to that of the precordial lead, it is not at all necessary to assume a potential of zero for the Wilson central terminal or other "indifferent" electrode point utilized to record the precordial lead. The in-

different electrode can have any electrical position in space. This represents a distinct advantage over the technique of comparing mirror patterns in which, as previously described, the potential of the Wilson central terminal introduces an error if it deviates from zero.

Investigators who have used the technique of comparing the contours of an actual lead with a lead derived from a spatial vectorcardiogram have concluded that, in general, the single resultant dipole concept can be applied reasonably well to percordial leads.[5,39,40] All have found some discrepancies and, in the final analysis, the degree to which the concept is accepted by each author is influenced greatly by the criteria which he utilizes to evaluate the resemblance between the parallel leads. The reviewer has occasionally observed, on a cathode-ray oscilloscope, precordial lead patterns having certain diagnostic features which could not be duplicated or even suggested by all possible spatial vectorcardiographic lead derivations formed simultaneously on a second oscilloscope.[5] He is, therefore, in complete agreement with den Boer[8] that a vectorcardiogram may supplement but cannot supplant multiple precordial leads.

Of perhaps more interest is a consideration of the possible explanation for the relatively satisfactory manner in which the dipole hypothesis may be applied to precordial leads in the majority of instances. It has been calculated that the theoretical error involved in the assumption that the voltages recorded in a chest lead are proportional to the component of a single vector is about 25 per cent when the exploring electrode is two heart diameters from the center of the heart and approximately 50 per cent when this distance is one diameter.[16] These calculations were based upon the assumption of a random distribution of electromotive forces (or dipoles) throughout the heart and herein may lie the explanation for the discrepancy between the calculated predictions and the experimental results with electrodes which, in some cases, may be situated even more closely than one diameter from the center of the heart. In the normal order of ventricular excitation, the simultaneous occurrence of more or less oppositely directed dipoles in the walls of the two ventricles has the effect of diminishing the effective size of the dipole cluster. In the reviewer's opinion the recently reported studies of intramural potentials with plunge electrodes[41-42] may be interpreted as indicating that the excitatory impulse is normally conducted through the Purkinje fibers to practically all portions of the myocardium in a more or less diminishing gradient of distribution from endocardium to epicardium.* This would be in accord with the anatomy of the Purkinje system[44] and would lead to a much greater cancellation of electrical forces within the ventricular walls than would be expected according to the traditional electrocardiographic concept of a wave of depolorization passing unidirectionally from the subendocardial to the subepicardial regions. Thus a widespread cancellation of forces could conceivably result in an apparent stabilization of the position of the assumed single resultant dipole center. The poor cancellations of mirror patterns obtained in patients with bundle branch block[33] indicate that asynchronous ventricular excitation

*Other investigations by Scher and associates[43] suggest, however, that the impulse is rapidly conducted in the subendocardial region from which it spreads more slowly into the ventricular walls, the cardiac muscle acting as a syncytium over which the impulse travels with a uniform velocity.

leads to a mobile resultant dipole center and probably to a larger effective cluster of individual dipoles. The observation[5] that the occurrence of a ventricular premature contraction produces marked differences between the configurations of a precordial and a derived lead when the normally occurring complexes are remarkably similar supports the same conclusion. Finally the fact that, for the most part, T waves in parallel leads are more dissimilar than the waves of their accompanying QRS complexes[5] further emphasizes the importance of mobility of the resultant dipole center, resulting in this instance from mechanical displacement of the heart immediately after depolarization.

The remaining factors, dipole eccentricity, tissue inhomogeneity, and limiting boundary irregularity, do not enter into discrepancies noted with comparisons of either mirror patterns or parallel effective leads (except as they influence the deviation from zero potential of the Wilson central terminal in the case of the mirror pattern technique). The important factors, however, are the effective size of the cluster of individual dipoles and the mobility of the assumed resultant dipole. The influence of these two factors cannot be properly separated. It has been suggested that the single resultant dipole concept can be upheld if its migration during the cardiac cycle is taken into account.[34,45,46] However, it is obvious that the more closely an exploring electrode approaches the heart, the less valid is the assumption of a single resultant dipole; the factor of mobility of such a resultant dipole becomes relatively less important as the assumptions underlying its existence become less tenable.

Since the single resultant dipole concept, as illustrated in Fig. 4, represents only an approximation, it would be of interest, before closing the discussion on precordial leads, to consider alternate methods by which a more exact representation can be depicted graphically. The possibility[47] of constructing a different lead vector for each significant change in the location of an assumed single resultant dipole center is hardly a satisfactory solution and certainly not a universal one. On the other hand, an electrocardiographic lead could be perfectly represented by an infinite number of lead vectors, one for each point within the myocardium where electromotive forces are generated. With such a theorectical representation, Equations (4) and (7) could be applied without any limiting assumptions. From a practical standpoint, lead vectors for many random points within the myocardium could be experimentally determined[48] and those having similar magnitudes and directions could possibly be averaged so as to reduce their total number. Thus the concept of a single resultant dipole could be applied to each of several regions of the heart rather than to the heart as a whole. A method is outlined in Part II of the appendix whereby the potential developed in each of these several regions of the heart might be calculated if sufficient experimental data were collected. Such an experimental approach should prove more satisfactory than attempting to determine the potential contributed by various portions of the heart from purely anatomic measurements made in conjunction with the concept of a solid angle subtended by a precordial electrode.[28] The latter technique does not take into account the fact that portions of the myocardium may not contribute any significant potential to body

surface leads,[41,42] nor are the factors of eccentricity, tissue inhomogeneity, and boundary irregularity adequately taken into consideration.

Another method of representing an electrocardiographic lead is by means of "flow lines"[16,49] or "tubes of influence".[50] Two-dimensional models, either hydraulic[49] or electric,[13] have been constructed to investigate and to display graphically the field of an electrocardiographic lead. Studies on such models have indicated that if a unit electric current is introduced into the body at the site of one electrode (source) and led off at the site of a second electrode (sink) the following factors determine the direction of flow of current and its density at any point within the body: (1) the location of the source and sink electrodes; (2) the size of these electrodes, which determines the current density in the regions of the source and sink; and (3) the varying resistances and configurations of the various organs and tissues and the external boundary configuration of the body. The experiments with hydraulic models[49] suggest that organs of varying density refract electric current in a manner analogous to the refraction of light by the various elements of a compound lens.

At any given point within the heart, the direction of flow of current would be identical with the direction of the lead vector between the two electrodes for that point. Likewise the current density at that point would be proportional to the magnitude of the lead vector. Therefore, it is possible to replace the mathematical concept of multiple lead vectors for each point within the myocardium by the physical concept of a "lead field" which would be developed when a unit current is introduced into an electrocardiographic lead.[16] The latter is more easily depicted graphically and has been well illustrated in several publications.[13,16,49,50]

b. Distant or remote leads: The multiple lead vector concept and the lead field concept, being universally applicable without any assumptions, can of course be applied to leads formed by electrodes located at relatively great distances from the heart. The hypothesis of a single resultant dipole involves the same assumptions for distant leads as for precordial leads, but such assumptions can theorectically be more easily upheld in the case of distant leads.

Although some investigators have utilized precordial leads in vectorcardiography,[51,52] the usual reference frames are formed of leads which are considered to be remote. For the most part these have consisted of various geometric configurations, such as a cube[6] or tetrahedron,[37] the axes of which have been determined by anatomic considerations. It is significant, however, that all investigators who have studied the Einthoven triangle in accordance with the exact physical and mathematical methods first described by Burger and van Milaan have found that a configuration similar to triangle *RLF* in Fig. 4, *A* is a much more accurate representation of the magnitudes and directions of the standard leads than is an equilateral triangle.[3,8,9,13,15] Moreover, similar studies indicate that other planes of the tetrahedron[37] and the planes of the cube[6] or rectilinear trihedron[40] show a much more marked discrepancy between their anatomic and electrical configurations than does Einthoven's frontal plane triangle.[3,9,16]

In the reviewer's opinion it is fortunate that vectorcardiographers have not as yet agreed to adopt any one of the many anatomically determined spatial reference frames suggested. Much work remains to be done before it is possible to decide whether a precise frame, based upon the lead vector concept, can be constructed. However, the concerted effort of various groups of investigators seeking such an ideal frame and defining its limitations, is well worthwhile for only thus can there be any hope of accurately depicting the electrical forces of the heart with such a simplified representation as a vector loop. In the remaining portion of this communication the author would like to make some comments and suggestions on possible methods of conducting such investigation. Four steps are involved:

(1) The torso diagrams recently published by Frank[9] and the concepts developed by McFee and Johnston[16] may be used for the preliminary selection of leads to be tested in Step 2. Groups of three leads may be so chosen as to have vectors which (a) are mutually perpendicular and also parallel to the x, y, and z coordinate axes or (b) are only very approximately perpendicular and not necessarily parallel to the coordinate axes. Leads of the type defined in (a) are required when conventional vectorcardiographic equipment is used.[6,37] Those of the type defined in (b) can be used only in conjunction with rotators such as the "universal vectorcardiograph"[53] or the "panoramic vectorcardiograph."[39]

By means of rotators, leads can be modified by coefficients[3,48,53] (determined accurately in Step 3) so as to yield x, y, and z components which are paired to form frontal, sagittal, and transverse plane vector loops. Leads of the type described in (b), while requiring more elaborate equipment, have the advantage of allowing electrodes to be placed on the extremities or neck or other reasonably well-defined and constant landmarks of the body.

(2) This step involves the testing of the tentatively selected leads to determine whether their electrode placements are satisfactorily remote, or expressed alternately, to determine whether the heart functions as a satisfactory single resultant dipole with respect to these leads. This step may be best carried out by choosing, with the aid of Frank's diagrams,[9] a "fourth lead" for each group of three leads (chosen in Step 1), which is likely to be as remote as any of the latter leads and not electrically parallel to any one of them. The actual testing then consists of comparing the simultaneously recorded "fourth lead" with a lead derived in such a way from the group of three leads that the lead vectors of the "fourth lead" and the "derived lead" are parallel and of equal magnitude. This may be done, as briefly described previously and more completely elsewhere,[5,39] by adjusting the coefficients of the three leads in such a way that the "fourth lead" and the "derived lead" demonstrate the closest possible resemblance. Qualitative criteria would have to be developed for judging objectively whether or not the heart was functioning as a satisfactory single resultant dipole with respect to the four leads. An alternative or supplementary method for quantitative measurement and statistical analysis would consist of reversing the polarity of the "fourth lead" and subjecting it to cancellation by the addition to it of the "derived lead." This could be done by suitable modification of the equipment used by Schmitt and his associates[31] but, as in their mirror

pattern studies,[31-33] would have the disadvantage of emphasizing only the maximal difference between the "fourth lead" and the "derived lead" without demonstrating their more subtle but perhaps equally significant variations to be noted upon direct comparison (on the same time scale) without cancellation. Such testing could be performed with various "fourth leads" on many individuals of different body types with both normal and abnormal hearts. If one or more groups of three leads could pass such rigid testing satisfactorily, each would be subjected to Step 3.

It should be noted in passing that the placing of an artificial dipole in a model at various locations corresponding to different points within the heart and demonstrating for each location a significantly different lead vector for any given lead is not a realistically satisfactory test for determining whether the lead would be sufficiently remote when used in conjunction with a living subject. Such a technique has been utilized to study the "remoteness" of the standard leads with the conclusion that the vectors of the latter vary significantly with different dipole positions.[48] However, in the light of the discussion under precordial leads of the factors which tend to reduce the effective size of the dipole cluster and to stabilize the location of the "single resultant dipole," it seems likely that such an approach may be unduly rigorous.

(3) Each of the groups of three leads found to be satisfactory in Step 2 should finally be studied in cadavers[8] or preferably in living subjects by the catheter technique, as suggested by McFee and Johnston[16] and briefly described previously. This would avoid the errors involved in using models containing a homogeneous medium[9] or media which are heterogeneous but which can only grossly approximate the resistances of the major organs of the body.[3] An artificial dipole would be placed in the heart of a cadaver or electrodes on a catheter would be placed in the living heart and the Principle of Reciprocity applied. (The latter technique could also be used alternately in the cadaver.) By means of the usual lead vector construction based upon the measured voltages, the placement of the electrodes of the three leads of any group could be varied slightly to produce vectors which were more nearly parallel to the x, y, and z coordinate axes ("type a" leads of Step 1) or the coefficients of the three leads could be adjusted so as to yield more precisely directed x, y, and z components ("type b" leads of Step 1). If the first type of adjustment involving change in electrode positions were gross, Step 2 should be repeated to be certain that the revised electrode placements remain satisfactorily remote. Step 3 should also be carried out with various body types to determine whether one set of electrode placements or coefficients is relatively satisfactory for all individuals or whether separate sets of electrode placements or coefficients must be devised for different morphologic groups.

(4) The lead vectors of all the "fourth leads" utilized satisfactorily in Step 2 should be experimentally determined along with the lead vectors of the three leads as just described in Step 3. Knowing the effective axes of all four leads, based upon an artificial dipole, the assumption might be made that they are identical for the living human heart. This assumption could then be tested by calculating the effective axis of the "derived lead" from the coefficients of its

component leads (determined in Step 2) and comparing it with the theoretically parallel effective axis of the "4th lead." The magnitude of the discrepancy, which, with multiple studies, could be expressed statistically, would provide another measure of how well the heart functions as a single resultant dipole for remote leads and would provide an over-all check of the accuracy of the experimental measurements made in Steps 2 and 3.

SUMMARY

Five factors which determine the accuracy of representing the electrical field of the heart by means of a spatial vectorcardiogram are:

1. The validity of representing multiple dipole centers within the heart as a single resultant dipole.
2. The variability of the location of the assumed single resultant dipole center during the cardiac cycle.
3. The degree of eccentricity of the assumed single resultant dipole center.
4. The lack of electrical homogeneity of tissues forming the volume conductor.
5. The irregularity of the limiting boundary of the volume conductor.

The last three factors influence the validity of utilizing reference frames devised according to anatomic considerations but can be eliminated by the use of reference frames, the electrical properties of which are determined experimentally and expressed in terms of the lead vector concept. The latter has been explained and illustrated in a detailed manner.

The first factor involves an assumption which becomes increasingly tenuous, the more closely one or more electrodes forming a lead approach the heart. Various methods, reviewed in detail, have been devised to assess the validity of this assumption. Such studies have indicated limitations of applying the concept of a single resultant dipole to precordial leads, although, in general, it would appear that such limitations are not as stringent as would be predicted from anatomic considerations. A possible explanation for this is discussed.

The second factor, migration of the assumed single resultant dipole center during the cardiac cycle, is related to and, from a practical standpoint, inseparable from, the first factor. It contributes to the shortcomings involved in applying the single resultant dipole concept to any electrocardiographic lead and is involved in the experimental evaluation of the validity of this concept.

A method is suggested for devising a spatial reference frame formed by remote leads which may obviate the last three factors and reduce to a minimum the influence of the first two.

In view of the limitations inherent in the single resultant dipole concept, alternate methods of representing the manner in which the electromotive forces arising in the heart influence an electrocardiographic lead are discussed. These comprise a mathematical representation consisting of multiple lead vectors, one for each point in the myocardium generating an electromotive force, and its physical counterpart consisting of "flow lines" or "tubes of influence" to depict the electrical characteristics of the lead field at each myocardial point.

A method is outlined in Appendix II for the application of the multiple lead vector concept to the experimental determination of the relative extent to which various portions of the heart contribute potentials to precordial leads.

APPENDIX I

With the aid of Fig. 3, Equation (2) may be derived in the following manner.
By construction,

$\overline{AE}$ and $\overline{CD}$ are parallel and of equal magnitude.
$\overline{B'E'}$ and $\overline{AC}$ are parallel.
$\overline{C'E'}$ and $\overline{AB}$ are parallel.

Then

$$\vec{AE'} = \vec{AB'} + \vec{AC'}$$

$$\frac{\overline{AB'}}{\overline{AB}} = \frac{\overline{CE'}}{\overline{BC}}$$

$$\frac{\overline{AC'}}{\overline{AC}} = \frac{\overline{BE'}}{\overline{BC}}$$

$$\frac{\overline{AB'}}{\overline{AB}} + \frac{\overline{AC'}}{\overline{AC}} = 1$$

Let $\frac{\overline{AC'}}{\overline{AC}} = q$; then $\frac{\overline{AB'}}{\overline{AB}} = 1 - q$ and

$$\vec{AE'} = (1-q)\ (\vec{AB}) + q\ (\vec{AC}) \quad .$$

Let $\frac{\overline{AE}}{\overline{AE'}} = Q$; then

$$\vec{CD} = \vec{AE} = Q(1-q)(\vec{AB}) + Qq(\vec{AC}) \quad . \tag{2}$$

APPENDIX II

A method of calculating from experimental data the relative contributions of various portions of the ventricular myocardium to any instantaneous QRS or T potential or to the mean QRS or T potential recorded by a precordial lead can be outlined as follows.

Equation (4) may be written in terms of the x, y, and z components of $\vec{e_1}, \vec{e_2}, \ldots \vec{e_n}$ and of $\vec{1_1}, \vec{1_2}, \ldots \vec{1_n}$ for points 1, 2, ...n located in the ventricles:

$$V = (e_{x1}\,1_{x1} + e_{y1}\,1_{y1} + e_{z1}\,1_{z1}) + (e_{x2}\,1_{x2} + e_{y2}\,1_{y2} + e_{z2}\,1_{z2}) + \ldots (e_{xn}\,1_{xn} + e_{yn}\,1_{yn} + e_{zn}\,1_{zn}) \quad . \tag{4'}$$

Let us next consider a number of points, a, b, c, d, ... located on the precordial surface (or anywhere on the chest). Let V_a, V_b, V_c, V_d, ... represent the recorded differences in potential between each of these points and the Wilson central terminal. Let $\vec{1_{1a}}, \vec{1_{2a}}, \ldots \vec{1_{na}}, \vec{1_{1b}}, \vec{1_{2b}}, \ldots \vec{1_{nb}}$, etc. represent the lead vectors when each of the myocardial points 1, 2, ...n is paired with each of the precordial points, a, b, ... etc. These lead vectors could be determined experimentally by placing a dipole in a suitable model or in a cadaver at the anatomic locations corre-

sponding to points 1, 2, ...n. If the number of precordial points chosen is equal to 3n, simultaneous equations of the following form and totaling 3n in number could be written:

$$V_a = (e_{x1}l_{x1a} + e_{y1}l_{y1a} + e_{z1}l_{z1a}) + (e_{x2}l_{x2a} + e_{y2}l_{y2a} + e_{z2}l_{z2a}) + \ldots (e_{xn}l_{xna} + e_{yn}l_{yna} + e_{zn}l_{zna}) \quad (4'')$$

$V_b = \text{etc.}$ $V_c = \text{etc.}$

Since all of the V terms and all of the l terms would be known from experimental measurements, the unknown terms, e_{x1}, e_{y1}, e_{z1}, e_{x2}, e_{y2}, e_{z2}, ... e_{xn}, e_{yn}, e_{zn}, whose number also equals 3n, could be calculated from these simultaneous equations.

From a practical standpoint it would be desirable, if possible, to reduce the number of precordial points and the number of equations to a minimum. Therefore, the possibility of grouping and averaging the precordial lead vectors for points within various regions of the ventricular myocardium should be explored by statistical analysis of the magnitudes and directions of these vectors.

REFERENCES

1. Frank, E., and Kay, C. F.: A Reference Potential for Unipolar Electrocardiographic Measurements on Models, AM. HEART J. **46**:195, 1953.
2. Wilson, F. N., and Bayley, R. H.: The Electric Field of an Eccentric Dipole in a Homogeneous Spherical Conducting Medium, Circulation **1**:84, 1950.
3. Burger, H. C., and van Milaan, J. B.: Heart Vector and Leads, I, Brit. Heart J. **8**:157, 1946. II, **9**:154, 1947. III, **10**:229, 1948.
4. Schaffer, A. I., Bergmann, P. G., Boyd, L. J., Mirkinson, A., and Beinfield, W. H.: Eccentricity as a Cause for the Difference Between the Vectorcardiograms Registered by the Cube and Tetrahedral Systems, AM. HEART J. **45**:448, 1953.
5. Helm, R. A.: The Vectorcardiographic Derivation of Scalar Leads, AM. HEART J. **46**:519, 1953.
6. Grishman, A., and Scherlis, L.: Spatial Vectorcardiography, Philadelphia, 1952, W. B. Saunders Company.
7. Grant, R. P., and Estes, E. H., Jr.: Spatial Vector Electrocardiography, New York, 1951, Blakiston Company.
8. Den Boer, W.: The Clinical Value of Vectorcardiography, Acta med. scandinav. **144**:217, 1952.
9. Frank, E.: The Image Surface of a Homogeneous Torso, AM. HEART J. **47**:757, 1954.
10. Frank, E.: General Theory of Heart-Vector Projection, Circulation Res. **2**:258, 1954.
11. Burger, H. C., and van Milaan, J. B.: Measurements of the Specific Resistance of the Human Body to Direct Current, Acta med. scandinav. **114**:584, 1943.
12. Bonjer, F. H., van den Berg, J., and Dirken, M. N. J.: The Origin of the Variations of Body Impedance Occurring During the Cardiac Cycle, Circulation **6**:415, 1952.
13. Brody, D. A., and Romans, W. E.: A Model Which Demonstrates the Quantitative Relationship Between the Electromotive Forces of the Heart and the Extremity Leads, AM. HEART J. **45**:263, 1953.
14. Den Boer, W.: Vectorcardiographie (A Thesis), Utrecht, 1951, Rijks Universiteit.
15. Wilson, F. N., Bryant, J. M., and Johnston, F. D.: On the Possibility of Constructing an Einthoven Triangle for a Given Subject, AM. HEART J. **37**:493, 1949.
16. McFee, R., and Johnston, F. D.: Electrocardiographic Leads. I. Introduction, Circulation **8**:554, 1953. II. Analysis, Circulation **9**:255, 1954. III. Synthesis, Circulation **9**:868, 1954.
17. Craib, W. H.: A Study of the Electrical Field Surrounding Active Heart Muscle, Heart **14**:71, 1927.
18. Selvini, A., Pilotti, A., and Lanza, F.: Etude vectorielle des dérivations electrocardiographiques, Cardiologia **16**:92, 1950.
19. Bayley, R. H., Reynolds, E. W., Jr., Kinard, C. L., and Head, J. F.: The Zero of Potential of the Electric Field Produced by the Heart Beat. The Problem With Reference to Homogeneous Volume Conductors, Circulation Res. **2**:4, 1954.
20. Bayley, R. H., and Kinard, C. L.: The Zero of Potential of the Electrical Field Produced by the Heart Beat. The Problem With Reference to the Living Human Subject, Circulation Res. **2**:104, 1954.
21. Wilson, F. N., Johnston, F. D., Rosenbaum, F. F., and Barker, P. S.: On Einthoven's Triangle, the Theory of Unipolar Electrocardiographic Leads and the Interpretation of the Precordial Electrocardiogram, AM. HEART J. **32**:277, 1946.
22. Dolgin, M., Grau, S., and Katz, L. N.: Experimental Studies on the Validity of the Central Terminal of Wilson as an Indifferent Reference Point, AM. HEART J. **37**:868, 1949.
23. Dolgin, M., Grau, S., and Katz, L. N.: Comparison of Precordial Electrocardiograms Obtained With CR, CL, CF and V Leads, AM. HEART J. **37**:333, 1949.
24. Grant, R. P.: The Relationship of Unipolar Chest Leads to the Electrical Field of the Heart, Circulation **1**:878, 1950.

25. Langner, P. H., Jr., Dewees, E. J., and Moore, S. R.: A Critical and Comparative Analysis of Methods in Electrocardiography Employing Mean QRS and T Vectors, Am. Heart J. **46**:485, 1953.
26. Simonson, E.: The Distribution of Cardiac Potentials Around the Chest in One Hundred and Three Normal Men, Circulation **6**:201, 1952.
27. Langner, P. H., Jr., and Atkins, J. P.: Intrabronchial Electrocardiography, Circulation **2**:419, 1950.
28. Schaefer, H.: Das Elektrokardiogramm, Theorie und Klinik, Berlin-Göttingen-Heidelberg, 1951, Springer-Verlag.
29. Böckh, E. M., and Schaefer, H.: Weitere Untersuchungen über die Konstruierbarkeit von Ekg.—Vektoren aus Brustwandableitungen, Cardiologia **23**:191, 1953.
30. Böckh, E. M., and Schaefer, H.: Versuche zur Berechnung der Vektoren aus Präkordialen Ableitungen, Ztschr. Kreislaufforsch. **41**:310, 1952.
31. Schmitt, O. H., Levine, R. B., and Simonson, E.: Electrocardiographic Mirror Pattern Studies, I, Am. Heart J. **45**:416, 1953.
32. Levine, R. B., Schmitt, O. H., and Simonson, E.: Electrocardiographic Mirror Pattern Studies, II, Am. Heart J. **45**:500, 1953.
33. Simonson, E., Schmitt, O. H., Levine, R. B., and Dahl, J.: Electrocardiographic Mirror Pattern Studies, III, Am. Heart J. **45**:655, 1953.
34. Duchosal, P. W., and Grosgurin, J. R.: The Spatial Vectorcradiogram Obtained by Use of a Trihedron and Its Scalar Comparisons, Circulation **5**:237, 1952.
35. Donzelot, E., and Milovanovich, J. B.: Aspects pratiques de la vectographie spatiale avec des remarques sur les axes des derivations unipolaires et l' exposé des limites de l' hypothèse d' Einthoven, Arch. mal. coeur **42**:352, 1949.
36. Jouve, A., Buisson, P., and Bergier, G.: Interprétation vectorielle et vectocardiographie. I. Leurs diffiicultés théoriques, Arch. mal. coeur **45**:30-39, 1952. II. Difficultés afférentes á la recherche du point origine des vecteurs et aux méthodes d' enregistrement, Arch. mal. coeur **45**:461, 1952.
37. Burch, G. E., Abildskov, J. A., and Cronvich, J. A.: Spatial Vectorcardiography, Philadelphia, 1953, Lea & Febiger.
38. Biber, D., and Schwartz, M. L.: Some Limitations of Vectorcardiography, Am. Heart J. **46**:161, 1953.
39. Milnor, W. R., Talbot, S. A., and Newman, E. V.: A Study of the Relationship Between Unipolar Leads and Spatial Vectorcardiograms, Using the Panoramic Vectorcardiograph, Circulation **7**:545, 1953.
40. Duchosal, P. W., and Sulzer, R.: La vectocardiographie, Basle, 1949, S. Karger.
41. Kennamer, R., Bernstein, J. L., Maxwell, M. H., Prinzmetal, M., and Shaw, C. M.: Studies on the Mechanism of Ventricular Activity. V. Intramural Depolarization Potentials in the Normal Heart With a Consideration of Currents of Injury in Coronary Artery Disease, Am. Heart J. **46**:379, 1953.
42. Prinzmetal, M., Shaw, C. McK., Jr., Maxwell, M. H., Flamm, E. J., Goldman, A., Kimura, N., Rakita, L., Borduas, J. L., Rothman, S., and Kennamer, R.: Studies on the Mechanism of Ventricular Activity. VI. The Depolarization Complex in Pure Subendocardial Infarction; Role of the Subendocardial Region in the Normal Electrocardiogram, Am. J. Med. **16**:469, 1954.
43. Scher, A. M., Young, A. C., Malmgren, A. L., and Paton, R. R.: Spread of Electrical Activity Through the Wall of the Ventricle, Circulation Res. **1**:539, 1953.
44. Abramson, D. I., and Margolin, S.: A Purkinje Conduction Network in the Myocardium of the Mammalian Ventricles, J. Anat. **70**:250, 1936.
45. Gillmann, H.: Über den Einfluss der Nahpotentiale, der Lage des elektrischen Nullpunktes und der Begrenzung des elektrischen Feldes auf die "unipolaren" Brustwandableitungen, Arch. Kreislaufforsch. **17**:284, 1951.
46. Gillmann, H.: Das "analysierte Potentialrelief" der unipolaren Brustwandableitungen, Ztschr. Kreislaufforsch. **41**:325, 1952.
47. Frank, E.: A Theoretic Analysis of the Influence of Heart-Dipole Eccentricity on Limb Leads, Wilson Central-Terminal Voltage and the Frontal-Plane Vectorcardiogram, Circulation Res. **1**:380, 1953.
48. Frank, E., and Kay, C. F.: Frontal Plane Studies of Homogeneous Torso Models, Circulation **9**:724, 1954.
49. McFee, R., Stow, R., and Johnston, F. D.: Graphic Representation of Electrocardiographic Leads by Means of Fluid Mappers, Circulation **6**:21, 1952.
50. Lepeschkin, E.: Modern Electrocardiography, vol. I, Baltimore, 1951, Williams & Wilkins Co.
51. Donzelot, E., Milovanovich, J. B., and Kaufmann, H.: Études pratiques de vectographie. Paris, 1950, Expansion scient. franç.
52. Jouve, A., Buisson, P., Albouy, A., Velasque, P., and Bergier, G.: La vectocardiographie en clinique, Paris, 1950, Masson & Cie.
53. Becking, A. G. T., Burger, H. C., and van Milaan, J. B.: A Universal Vector Cardiograph, Brit. Heart J. **12**:339, 1950.

Book Review

DER HERZ-KATHETERISMUS BEI ANGEBORENEN UND ERWORBENEN HERZFEHLERN. By Otto Bayer, Franz Loogen and Helmut Wolter. Stuttgart, 1954, Georg Thieme Verlag. 191 pages with 131 figures.

Heart catheterization originated in Germany (W. Forssmann, 1929, to whom the book is dedicated), but was practically forgotten there for about twenty-five years. It was only after the pioneering work of American authors that the method was reintroduced in Germany, and it is used now on a rather large scale. While this monograph is based mainly on the material of 800 catheterizations performed by the authors during the past five years at the University Hospital in Düsseldorf, the discussion is quite comprehensive with a bibliography of twelve pages.

In the introductory chapters there is a condensed description of equipment and technique, which includes well-known methods (such as Haldane gas analysis), as well as interesting new developments, such as the use of Neuhaus' capacitance manometer for pressure recording, or the measurement of the oxygen saturation with photometry of reflected light. A following chapter concerns the evaluation of results, including analysis of pressure curves and the various equations for calculating shunts, resistances, valvular areas, etc. Because of the inaccessibility of the pulmonary veins, the authors make the simplifying assumption that the oxygen saturation of pulmonary venous blood is 96 per cent in all cases without impairment of diffusion. Of particular interest is the chapter on complications (Chapter VI, pp. 51 to 61). The instructions given in the first 60 pages are so complete that no or little additional information is needed for application of this method. In the second part (pp. 62 to 171), there is a systematic discussion of heart catheterization in the various types of congenital heart disease, mitral stenosis and insufficiency, with an appendix on the changes after mitral stenosis surgery. The excellence of the presentation is matched by the excellence of the numerous illustrations. To the knowledge of the reviewer, this book has no equivalent on an international scale and can be recommended without reservation.

E. S.

Announcements

Beginning in the March, 1955, issue of the AMERICAN HEART JOURNAL an abstract of each article will appear in INTERLINGUA.

The University of Minnesota announces a continuation course in RECENT ADVANCES IN INTERNAL MEDICINE FOR INTERNISTS which will be presented at the Center for Continuation Study from Feb. 14 to 16, 1955. This year's course will deal with various aspects of hematology, cardiology, endocrinology, and respiratory physiology. The course will be presented under the direction of Dr. C. J. Watson, Professor and Director, Department of Medicine. Lodging accommodations will be available at the Center for Continuation Study.